DEVELOPMENT OF A FLOOD-FREQUENCY MODEL FOR THE RIVER BASINS OF THE CENTRAL REGION OF MALAWI AS A TOOL FOR ENGINEERING DESIGN AND DISASTER PREPAREDNESS IN FLOOD-PRONE AREAS

by

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I declare that ***Development of a Flood Frequency Model for the River Basins of the Central Region of Malawi as a Tool for Engineering Design and Disaster Preparedness in Flood-Prone Areas*** is my own work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references.

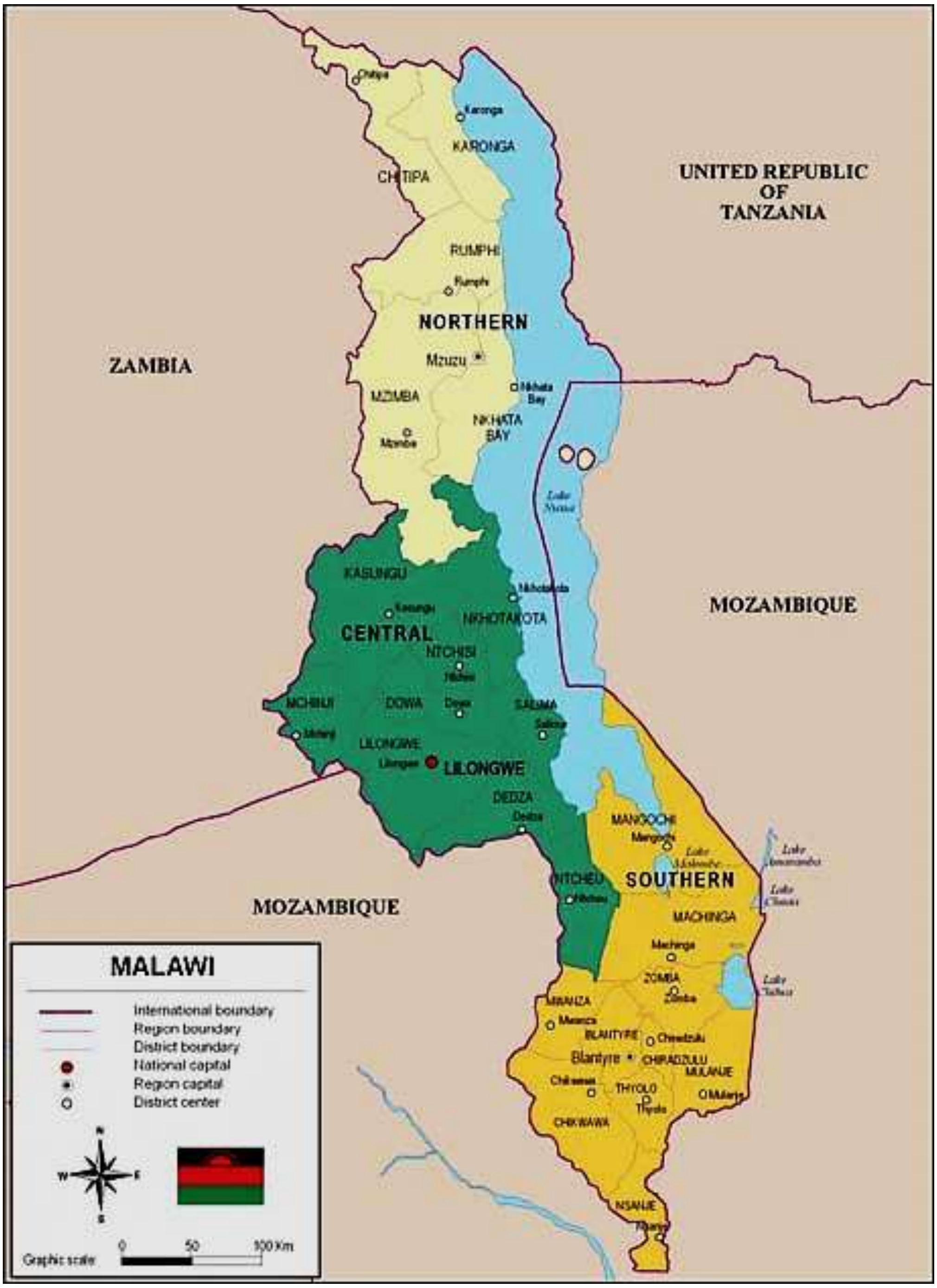
September 23, 2016

SIGNATURE (Mr.)	DATE

DEDICATION

This dissertation is dedicated to all those who over the decades have worked tirelessly to collect and archive hydrometric data so that scientifically-based decisions could be made from the ensuing analysis of river discharges in order to improve the welfare of the people of Malawi. The commitment and perseverance of a Gauging Assistant wading across a raging river to measure its flow rate is not only a true spirit of bravery but a clear sign of loyalty to this cause. In light of the above, this study is a special appreciation and honour to all Gauging Assistants in Malawi who have contributed immensely to the development of hydrological analysis in the country, particularly those who taught me how to take discharge measurements of our rivers.

THE CENTRAL REGION OF THE REPUBLIC OF MALAWI



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ABSTRACT

Since 1971, a number of flood frequency models have been developed for river basins in Malawi for use in the design of hydraulic structures, but the varied nature of their results have most often given a dilemma to the design engineer due to differences in magnitudes of calculated floods for given return periods. All the known methods for flood frequency analysis developed in country so far have not used a homogeneity test for the river basins from which the hydrological data has been obtained. This study was thus conducted with a view to resolving this problem and hence improve the design of hydraulic structures such as culverts, bridges, water intake points for irrigation schemes, and flood protection dykes.

In light of the above, during the course of this study the applicability of existing methods in the design of hydraulic structures was assessed. Also, the study investigated how land use and land cover change influence the frequency and magnitude of floods in the study area, and how their deleterious impacts on the socio-economic and natural environment in the river basins could be mitigated.

Key Terms

Flood frequency, homogeneity test, hydraulic structures, land use and land cover change, return period.

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ACRONYMS AND ABBREVIATIONS

ADC	Area Development Committee
a. m. s. l	above mean sea level
APFM	Associated Programme on Flood Management
AVHRR	Advanced Very High Resolution Radiometer
CA	Catchment Authority
CEDRISA	Centre for Development Research and Information in Southern Africa
CEPA	Centre for Environmental Policy and Advocacy
CISANET	Civil Society Agriculture Network
DoDMA	Department of Disaster Management Affairs
DfID	Department for International Development
DPSIR	Drivers-Pressure-State-Impact-Response (framework)
FAO	Food and Agriculture Organization
GDI	Gross Domestic Income
GDP	Gross Domestic Product
GVH	Group Village Headperson
GWP	Global Water Partnership
IOD	Indian Ocean Dipole
IUCN	World Conservation Union
IWRM	Integrated Water Resources Management
IMF	International Monetary Fund
LUANAR	Lilongwe University of Agriculture and Natural Resources
LULC	Land use land cover
LWB	Lilongwe Water Board
MGDS	Malawi Growth and Development Strategy
MK	Malawi Kwacha
MoAFS	Ministry of Agriculture and Food Security
MODIS	Moderate Resolution Imaging Spectroradiometer
NCA	Norwegian Church Aid
NGOs	Non-Governmental Organisations
NIWA	National Institute of Water and Atmospheric Research
NRC	Natural Resources College
NWRA	National Water Resources Authority
PANA	Pan-African News Agency

RGS	River Gauging Station
ROSA	Regional Office for Southern Africa
SADC	Southern African Development Community
SARDC	Southern African Research and Documentation Centre
SLM	Sustainable Land Management
SST	Sea Surface Temperature
STA	Sub-Traditional Authority
TA	Traditional Authority
UCAR	University Corporation of Atmospheric Research (of Colorado)
UNDP	United Nations Development Programme
UNDRO	United Nations Disaster Relief Organisation
UNEP	United Nations Environment Programme
UNFPA	United Nations Population Fund
UNICEF	United Nations Children Fund
UNIMA	University of Malawi
UNISA	University of South Africa
US	United States
USAID	United States Agency for International Development
VDC	Village Development Committee
WFP	World Food Programme
WHO	World Health Organization
WRA	Water Resources Area
WRI	World Resources Institute
WRU	Water Resources Unit
ZAB	Zaire Air Boundary
ZAMCOM	Zambezi River Basin Commission

DEFINITIONS

Agro-based	Relying on agriculture and its products
Bank	The left and right limits of a river channel
Bar	A rock ledge; a solid hump within a river channel
Biomass	The total mass of living or dead organisms or matter within a given area
Confluence	Point at which two rivers meet; where a tributary joins the main river
Culvert	An opening, cylindrical or otherwise that carries water under a road or railway line
Cyclone	Wind system that rotates inwards from an area of high pressure to an area of low pressure; a wind depression commonly associated with heavy precipitation.
Dam	A barrier either of earth or concrete across a river behind which forms a reservoir of water
Degrade	Reduce in value or ability to function effectively
Discharge	Flow; amount of fluid such as water passing through a particular point towards a certain direction per unit of time such as second or minute
Driver	Fundamental cause; genesis of an event or action
Drought	Absence, scarcity or deficiency of precipitation
Ecosystem	Area or region having own characteristics in biophysical

	elements
Escarpment	An inclining ridge or range that extends from a relatively flat region and slopes towards a lower and another flat zone
Exotic	Not native to a region or area
Extrapolate	Infer upwards
Flood	Huge amount of water often occurring after precipitation that can inundate the land; excessive flow
Flow	Discharge
Fragile	Capable of being destroyed or damaged easily
Gauge	Measure
Gini-index	Also called the *Gini-coefficient*. A measure of the degree of deviation of the income distribution or consumption among individuals (or households) from a perfectly equal distribution
Gross Domestic Income	The total income created in-country and abroad
Gross Domestic Product	The total output produced by a country
Headwaters	The farthest areas of a river or stream from its estuary or confluence with another river
Heterogeneous	Diverse in characteristics, properties or nature
Homogeneous	Having similar, same or nearly same characteristics, properties or nature

Humidity	The amount of moisture in a given volume of air
Hydraulic	Related to, denoting or operated by a liquid (such as water, oil etc.) that is moving in a confined space (such as through spillways, gates, culverts, pipes etc.)
Hydrograph	A graph that shows or depicts the rate of flow (discharge) against time past a specific point in a river, or other channel or conduit that is carrying flow
Hydrometry	The monitoring of the components of the hydrological cycle including rainfall, groundwater, water levels, discharge, water quality etc. within a particular basin
Impact	Effect or bearing upon something as a result of a cause or pressure
Indigenous	Native to a region or area; not foreign or of foreign origin
Infiltrate	Enter or permeate into the soil
Inselberg	A hill or mountain that is isolated and rises abruptly from a plain
Instantaneous	Occurring rapidly, instantly or immediately; occurring momentarily
Knoll	A small low and round hill appearing on a generally flat or undulating plain
Ledger	Record book or file. In Hydrometry: a book containing records of water levels, flow measured and by whom, the date of measurement, instruments used etc.
Levée	An embankment that is constructed in order to prevent water

	from overflowing the confines of the channel
Marsh	An area which is generally low-lying and prone to being flooded and inundated during the wet season and is almost entirely water-logged during most parts of the year
Massif	A group of mountains forming one super-mountain that is separate from others
Miscellaneous station	A hydrometric station or a selected point on a river or stream which is not designated as a hydrometric station from where measurements of water levels, flows and other parameters are made specifically for non-routine purposes
Orographic	Being caused by the lifting of moist air as it rises over high ground
Peneplain	A relatively flat or level terrain that has been created or caused by erosion over many millenia of years
Percolate	Movement of a liquid such as water through a porous medium; movement of water from the upper layer of the soil to the weathered rock below this stratum
Plateau	An area consisting of high terrain that is usually flat at the top. Land with the formation of a table
Precipitation	The falling to the ground of snow, hail, rain, mist, fog etc. over an area
Pressure	An action, event or occurrence that changes the original form of a region, area or an ecosystem
Primary station	In hydrometry: a regular gauging station with an automatic water level recorder, staff gauges, high-flow water-level

	measuring facility and forming part to a network that is regularly maintained and managed
Probability	Chance, likelihood
Rain-fed	Depending entirely on occurrence of rainfall, e.g. rain-fed agriculture
Rating curve	Relationship between two variables such as water level and flow at that level
Recorder	Person or instrument that records information such as for instance, water levels
Response	Act of responding to an event
Return period	Period within which an event is expected to occur once on average since it last occurred; period of repeating occurrence of that magnitude once on average in those many years
Staff-gauge	Metal (or other form) plate that is graduated, placed and anchored from point of no flow to the highest point on the banks of a river or stream used for measuring water levels
Stage	Height, level, e.g. water level
State	Condition
The Commons	Areas of communal resources harvest and use, where entry is unrestricted
Trading Centre	Usually rural semi-urban settlement with residential, commercial and small industrial settings
Tributary	One or more of the branches of a river or stream that joins it

Undulating	Rolling; having gentle and smooth wavy slopes
Velocity	Distance of movement in a particular direction over a unit of time
Weir	A structure in the form of a barrier that is constructed across a river or stream usually designed for measurement of its flow

CHAPTER 1
BACKGROUND

1. Introduction

In the design of hydraulic structures such as culverts, bridges, water intake works for irrigation schemes and flood protection dykes the need to use appropriate values of flood magnitudes for specific return periods cannot be overemphasized (Mays, 2001; Chow et al, 1988; Shaw, 1983). This is particularly true where design floods have been underestimated, resulting in the wash-away of roads and bridges and the breaching of flood protection dykes, with serious repercussions on loss of life and damage to property. It was for this reason that the current study was conducted so as to improve the ability by engineers to accurately determine flood magnitudes for specific return periods in river basins in the Central Region of Malawi by homogenising the various existing flood frequency models.

Past experience has shown that several models developed so far in Malawi give varied results, posing a serious challenge to the design engineer. In light of the above, findings of this study will go a long way in saving lives and property in Malawi from disasters associated with floods through improved designs of hydraulic structures. The study also investigated factors that influence the occurrence of floods in the Central Region of Malawi and proposed measures for flood mitigation.

1.1 Location of the Study Area

Administratively, Malawi is divided into three regions (Figure 1) with a total of 28 districts. The Northern Region has six districts, namely: Chitipa, Karonga, Rumphi, Mzimba, Nkhata Bay and Likoma while the Central Region is made up of Kasungu, Nkhotakota, Ntchisi, Dowa, Mchinji, Lilongwe, Salima, Dedza and Ntcheu, totalling nine districts. The Southern Region consists of Balaka, Machinga, Mangochi, Zomba, Neno, Mwanza, Chiradzulu, Thyolo, Phalombe, Mulanje, Blantyre, Chikwawa and Nsanje totalling thirteen districts.

The Central Region lies between latitudes 12° 07′ South and 14° 30′ South and longitudes 32° 40′ East and 34° 37′ East (Figure 1). The watershed between the South Rukuru and the Dwangwa River Basin defines the northern boundary of the region while the Livulezi River defines the southern hydrological frontier. To the south-west the Central Region is marked by the international boundary between Malawi and Mozambique while the international boundary between Malawi and Zambia forms the western frontier of the region. The western shore of Lake

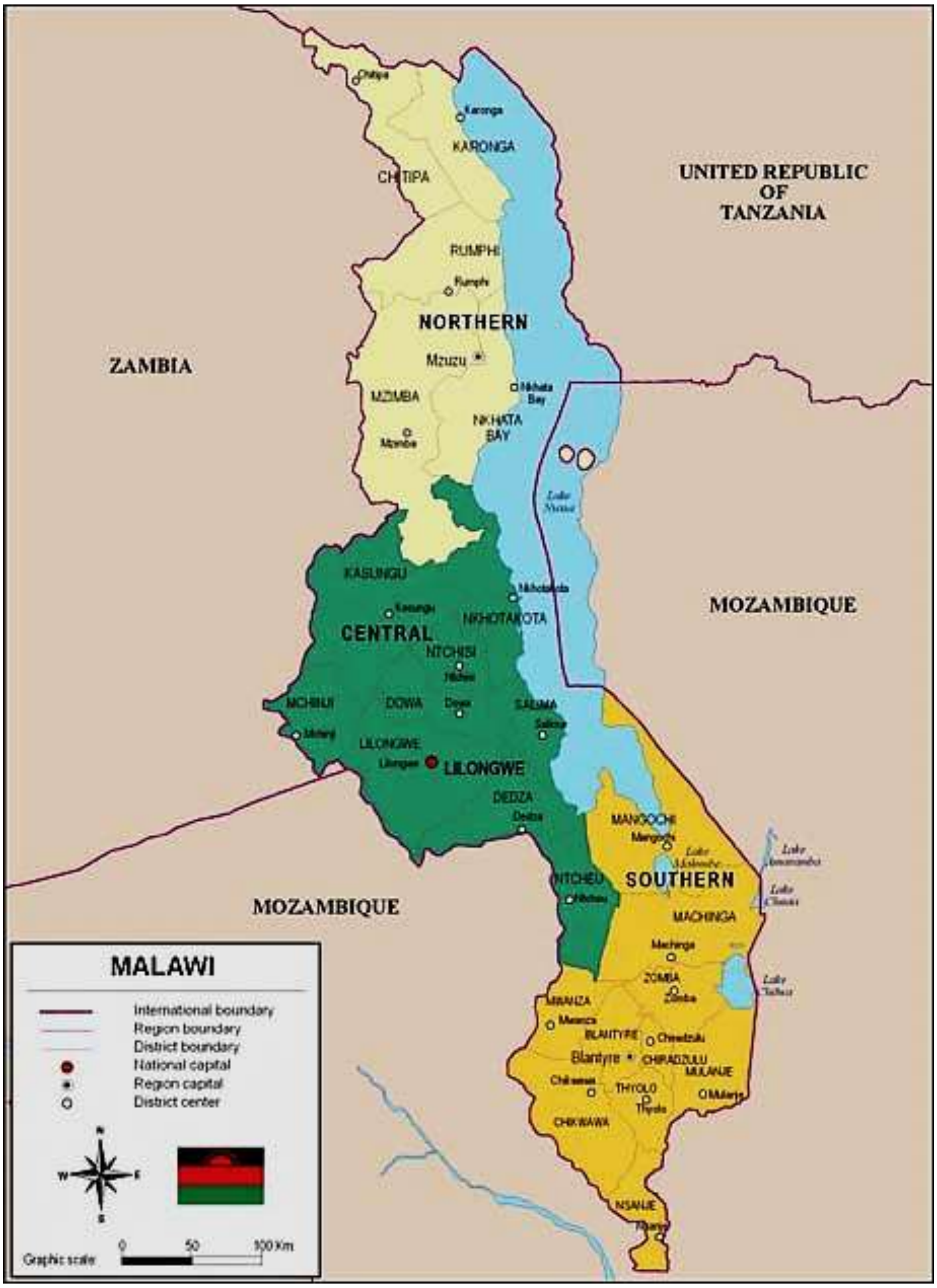

Figure 1: Map of Malawi showing the location of the Central Region (in green colour).

marks the eastern limit of the study area.

1.2 Economic Status and Population

Malawi's economy is agro-based in nature with agriculture accounting for more than 80 per cent of export earnings, contributing 36 per cent of gross domestic product (GDP), and providing a livelihood for 85 per cent of the population. Smallholder farmers contribute about three-quarters of agricultural production, dominated by a maize-based rain-fed cropping system. Agriculture growth accelerated from around 4 per cent in 2004/05 to around 14 per cent in 2006/07 and to around 13 per cent in 2008/09. Within the same period the economy grew by 8.6 per cent in 2007, 9.7 per cent in 2008 and 7.6 per cent in 2009.

Over-dependence on rain-fed agriculture has led to low agricultural production and productivity due to weather shocks and natural disasters (unreliable rainfall patterns, erratic rains, dry spells, pest and diseases, droughts, floods etc.). The other important sectors apart from agriculture production are distribution, with 20.8 per cent; manufacturing, 10.9 per cent; financial and professional services, 9.1 per cent; and producers of government services, 8.2 per cent (Government of Malawi, 2011).

Malawi's population is estimated to be 17 million, and growing at a rate of approximately over two per cent per annum. About 85 per cent of the population continues to live in rural areas. Over 90 per cent of the rapidly growing population in the country is sustained by small-scale agriculture with associated pressure on the land base, as increasingly marginal lands comprising steep slopes and fragile lands are brought into production (Mkanda, 2002; and Hecky *et al*., 2003).

Appendix A shows the population of the Central Region from 1998 to 2014 and this information is presented on Figure 2 (GoM, 1998). In this Figure the district populations have been plotted individually to show the general progression of population increase from 1998 to 2014 while a combined total which represents the regional population is also indicated on the same graph.

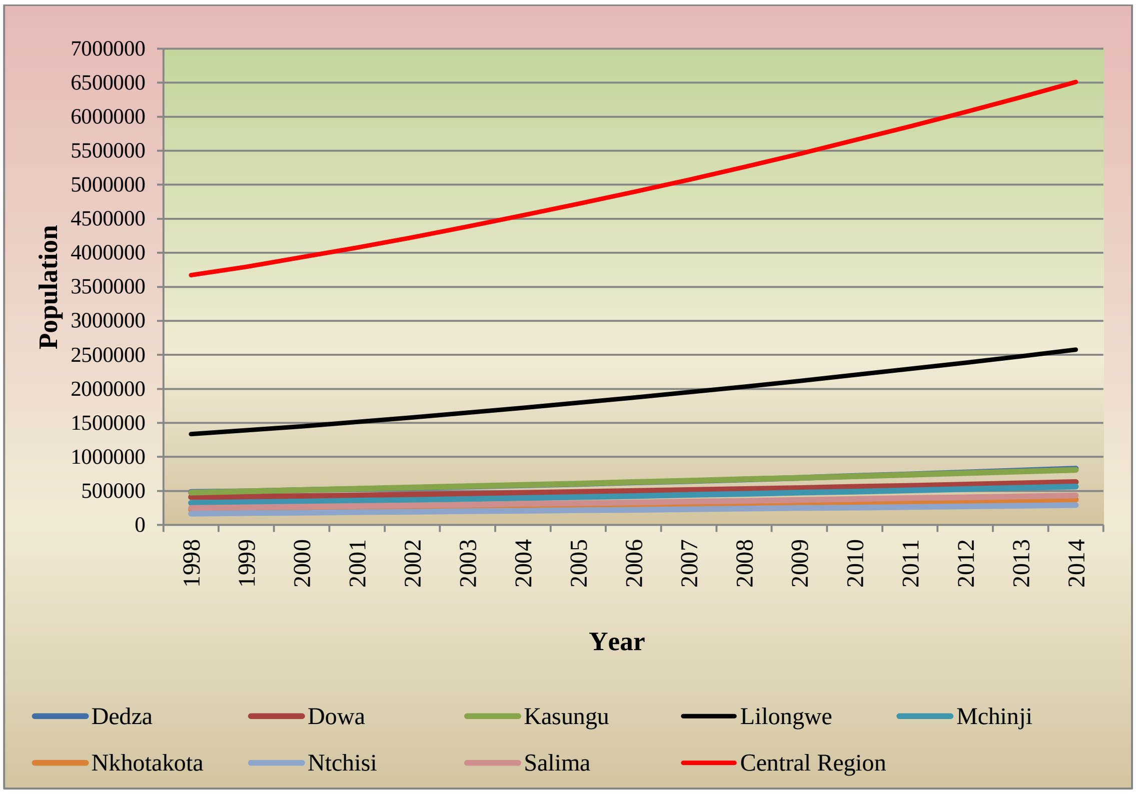

Figure 2: Population of the Central Region by district (1998 - 2014)

Source: Produced from data from the National Statistical Office, Zomba

Thus, the population of Central Region has increased steadily from 3,671,719 in 1998 to 6,510,786 people in 2014 (GoM, 1998) and it is projected to increase to 9.8 million people by the year 2025.

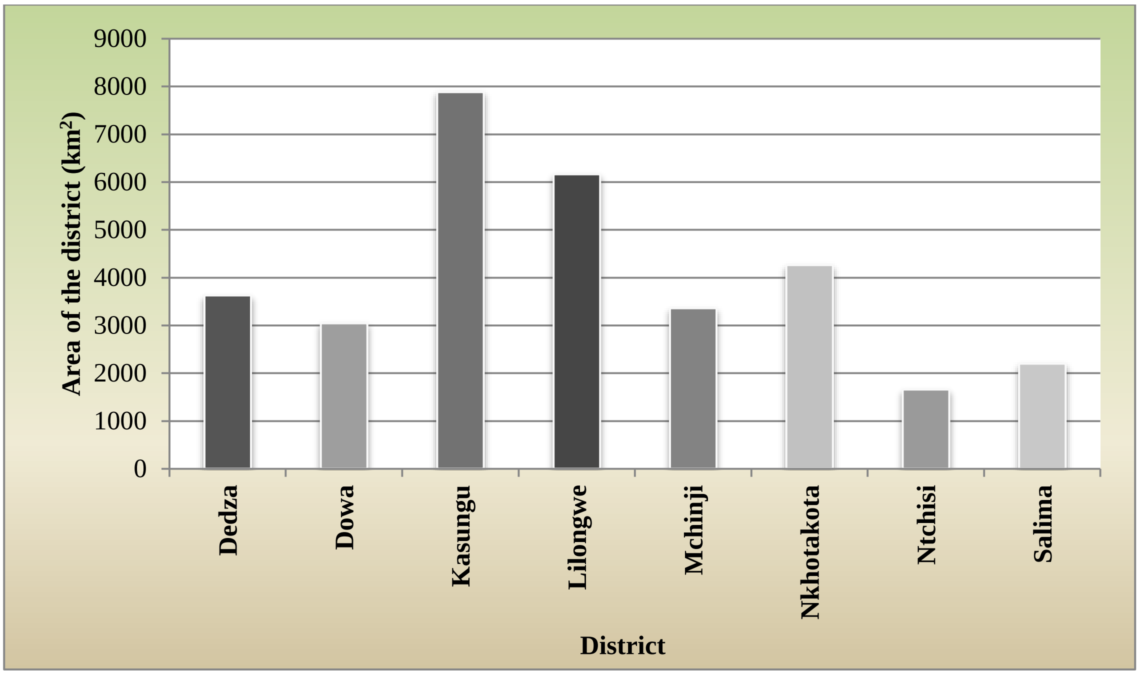

Figure 3: Geographical areas of the eight districts (km^2)

Source: Produced from geographical data of the eight districts

Population within the region is concentrated in the districts of Dedza (829,726 people), Dowa (631,879), Kasungu (808,673), Lilongwe (2,575,533) and Mchinji (565,601). The other districts have comparatively smaller population figures of less than half a million people, Salima with 434,508 people, Nkhotakota 372,314, and Ntchisi 292,552 (GoM, 1998). Figure 3 shows the geographical areas of the eight districts under study within which are concentrated the respective population of people. From the available information presented in Figure 3, population densities for each district were calculated and these appear in Table 1.

The significance of including population statistics in this study is that people population sizes have a direct bearing on the use of natural resources (land, forests, water, etc.) within the area of interest, with consequent influence on the dynamics of runoff from the various river basins as land resources get modified. For instance Figure 4 shows how densely populated the region is towards the south and south-western corners which means that there is high demand for land for cultivation and settlement, with adverse impacts on surface runoff.

Table 1: Population densities of the eight districts in 2014 (people/km^2)

District	Area (km^2)	Population in 2014	Population density (people/km^2)
Dedza	3624	829,726	229
Dowa	3041	631,879	208
Kasungu	7878	808,673	103
Lilongwe	6159	2,575,533	418
Mchinji	3356	565,601	168
Nkhotakota	4259	372,314	87
Ntchisi	1655	292,552	177
Salima	2196	434,508	198
Regional mean population density			**198**

Source: Calculated from data from the National Statistical Office, Zomba

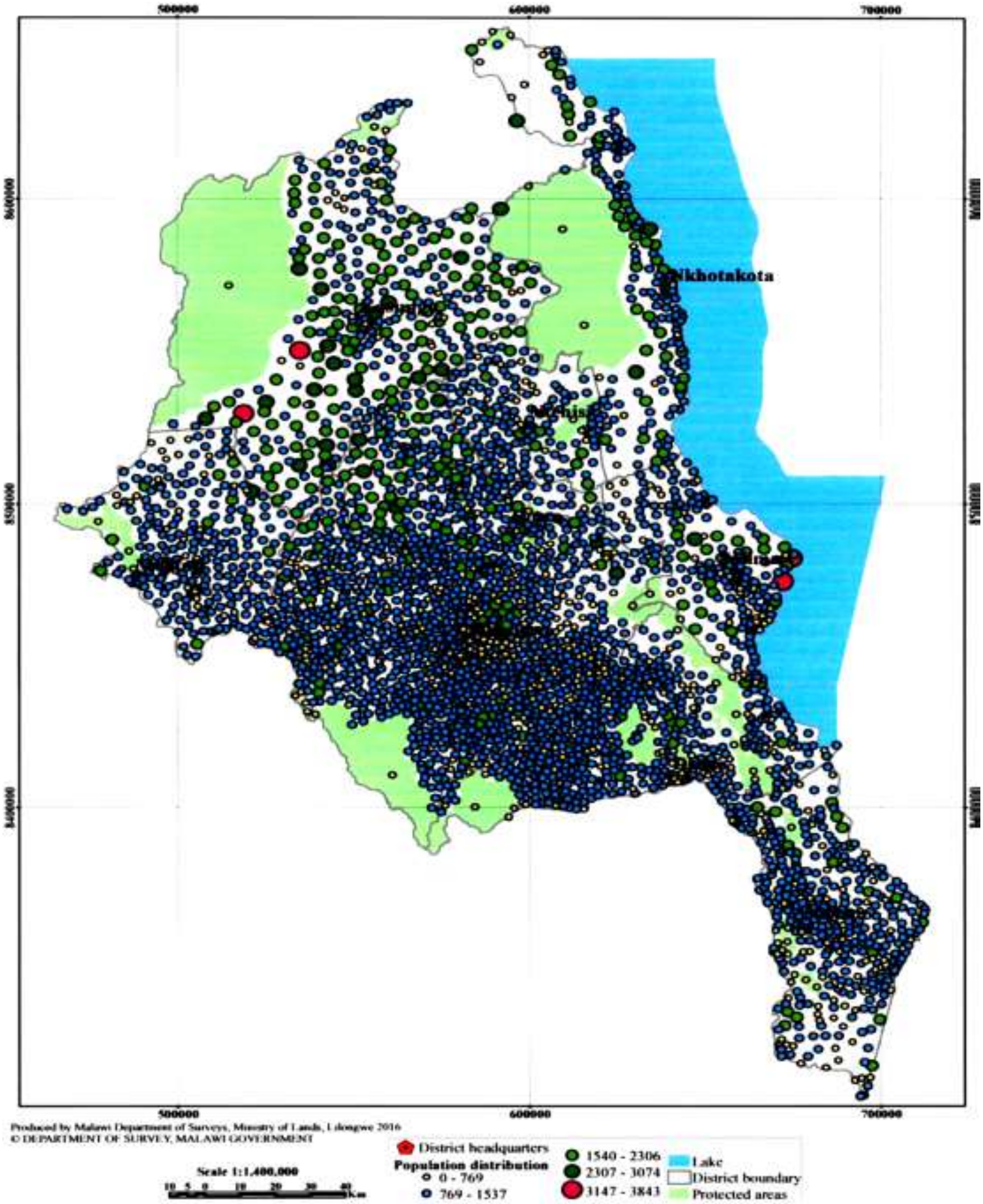

Figure 4: Population distribution in the Central Region of Malawi

Malawi does not at the moment have any significant mining entreprises having only contributed 3 per cent to the GDP prior to 2009 when the Paladin Uranium mine was opened in Karonga (NCA et al, 2014). The generation of foreign currency is therefore going to depend on agriculture for some time to come as Kachule (undated) states that if the national economy were to maintain an annual growth rate of 6 per cent, it would require that the agricultural sector maintains a growth rate of 15 per cent per annum. Such a growth rate would be a catalyst for further environmental degradation.

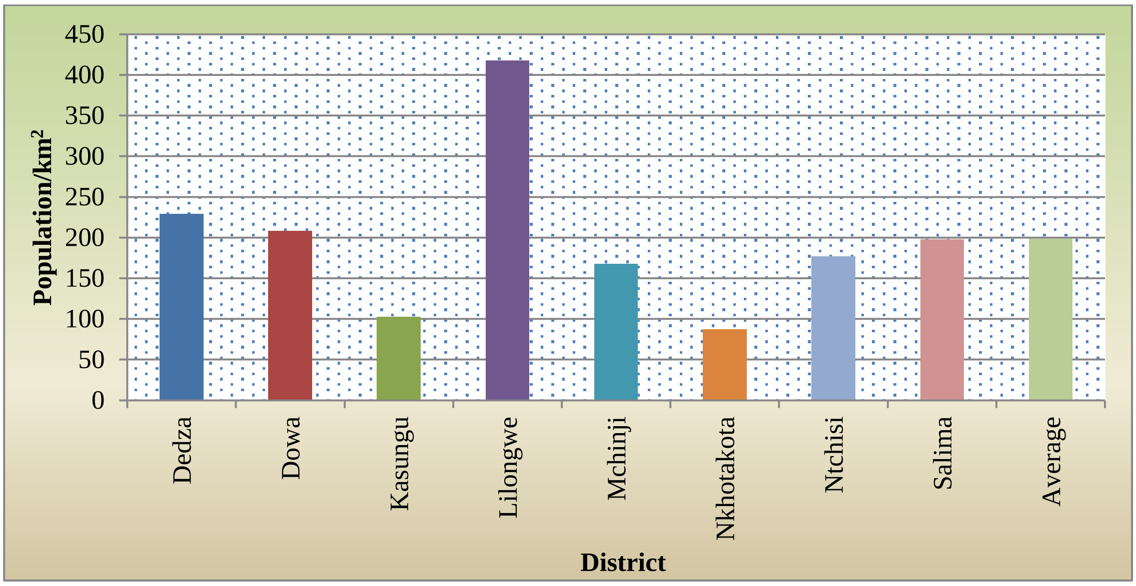

Figure 5: Population densities of the districts of the Central Region in 2014 (people/km^2)

Source: Produced from data in Table 3

As will be seen from Figure 5 the Central Region had an average population density of close to 200 people/km^2 in 2014 and with growth in population, population density will rise further with the resultant increasing preassure on the natural resource base.

1.3 Climate

The Central Region, like the rest of the country, experiences a tropical-continental climate with two distinct seasons, namely: a wet season from November to April and a dry season from May to October (Chavula 2008). The dry season is characterized by strong south easterly trade winds (locally known as the *Mwera*) that blow over the region while during the wet season the winds are generally north easterly (*Mpoto*) and weaker. The Inter Tropical Convergence Zone (ITCZ), the Zaire Air Boundary (ZAB), and tropical cyclones (Figure 6) are the three large-scale synoptic systems that bring rainfall to the study area (Kululanga and Chavula, 1993).

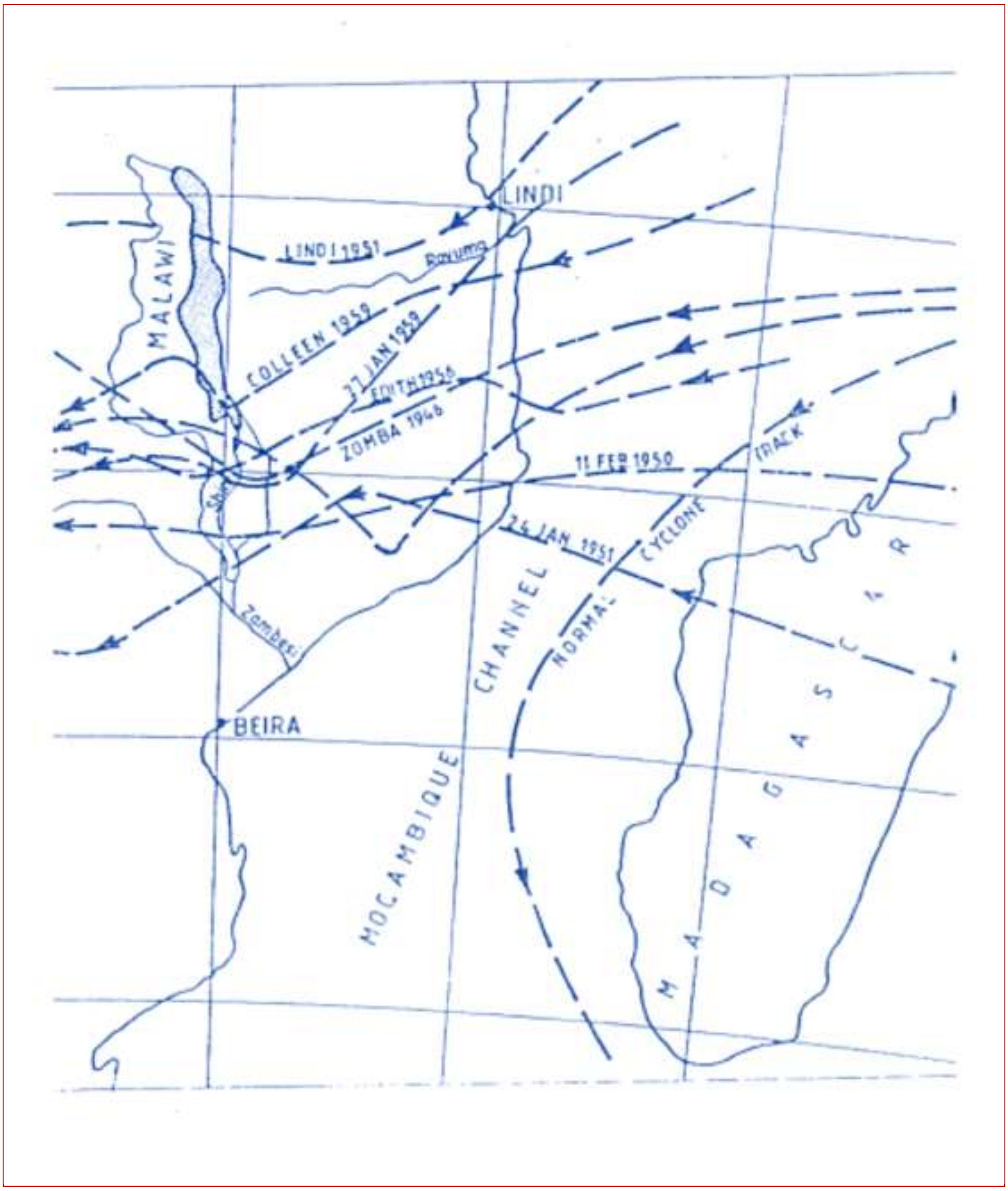

Figure 6: Cyclone Track (Source: Water Department/UNDP, 1986)

As pointed out in the preceding discussion, the climate is strongly influenced by the seasonal migration of the Inter-Tropical Convergence Zone (ITCZ) over East Africa (McHugh and Rogers, 2001). Unlike some countries to the north, Malawi experiences unimodal rainfall season, during the Austral summer, when the ITCZ is at its southernmost position. Air temperatures during austral summer typically range from 23º to 33ºC. During the austral winter, when the ITCZ is far to the north of Malawi, air temperatures drop to 15 – 27º C. This is the dry season, when strong southerly winds (*the Mwera*) prevail much of the time.

The regional climate is also affected by the south eastern Africa convergence zone, formed by three surface airstreams: the southeast trade winds coming off the Indian Ocean, the north-easterly monsoon, and the Atlantic air mass derived from the west (Nicholson, 1996; McHugh and Rogers, 2001). Rainfall variability associated with this convergence in southern East Africa has been attributed to sea surface temperature (SST) characteristic in the South Atlantic Ocean, the equatorial Pacific, and the Indian Ocean, as well as to the North Atlantic Oscillation (McHugh and Rogers, 2001).

However, the dominant pattern of influence appears to be a dipole structure in the Indian Ocean SST field: when the western (eastern) Indian Ocean is warm (cool), the Indian Ocean Dipole (IOD) is considered positive, easterly winds are enhanced across the equatorial Indian Ocean, and East Africa generally experiences high rainfall. The IOD is essentially the Indian Ocean version of the Pacific Ocean warming, which, during a negative phase, causes warmer wetter condition in the eastern Indian Ocean and cooler, drier conditions in the western region.

The pattern of inter-annual variability in rainfall in eastern and southern Africa is dipolar, with years of anomalously high (low) rainfall in tropical east Africa matched by years of anomalously low (high) rainfall in southern Africa (McHugh and Rogers, 2001). Such conditions tend to prevail during El Nino (La Nina) conditions, when the Indian Ocean Dipole (SST pattern) is positive (negative).

Nicholson *et al.*, (2013) divided Malawi into four homogeneous rainfall regions as depicted by Figure 4. Table 1 shows rainfall onset, end, and duration whereas Figure 5 shows mean annual and seasonal rainfall in mm (based on the period 1962 - 2009). It is clear from Figure 4 that the Central Region mostly falls in Zones 1, 2, and 3.

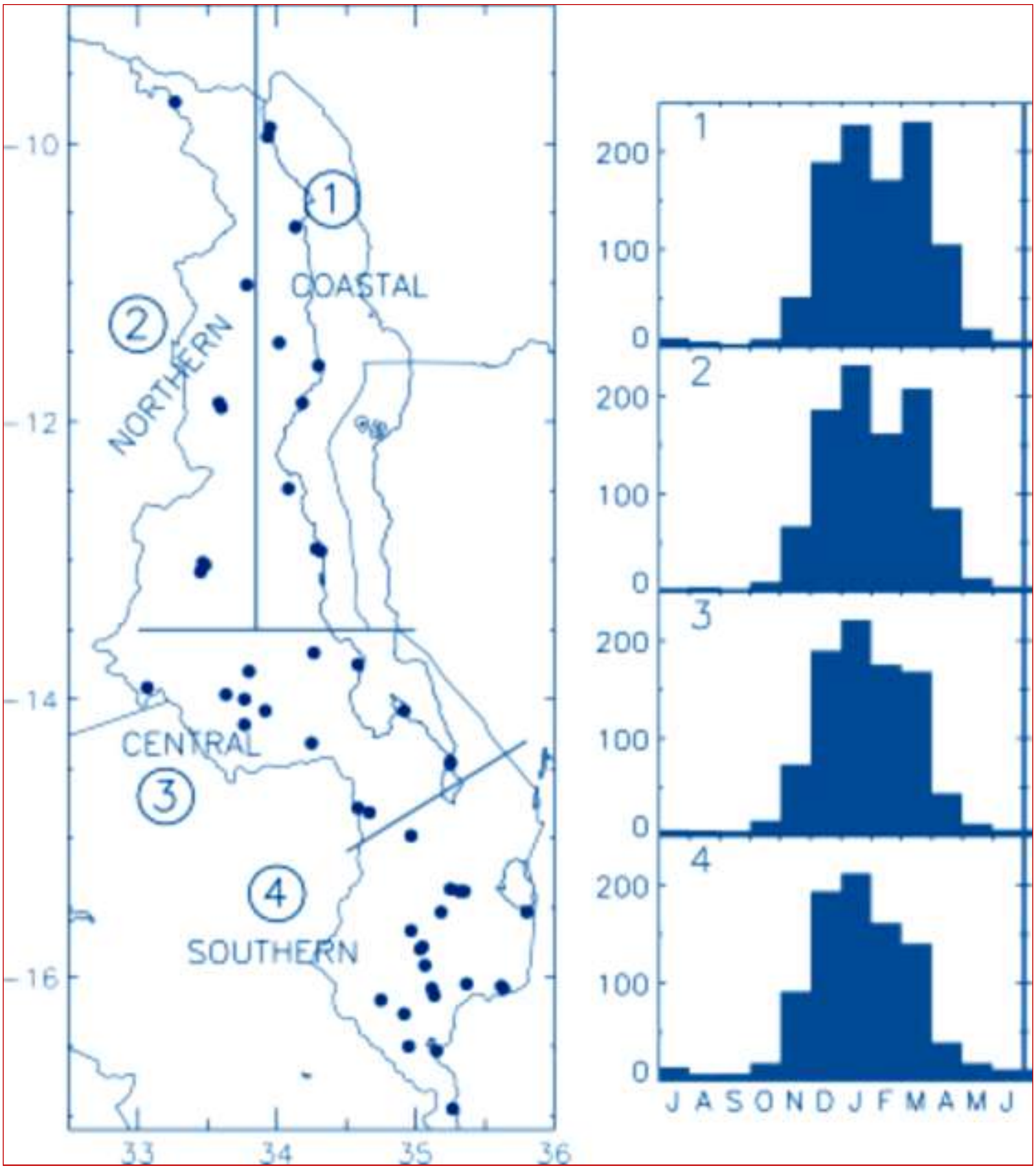

Figure 7: Four homogeneous rainfall regions of Malawi and the stations within them.
Right: The typical seasonal cycle of rainfall (mm per month) in each region

Source: Nicholson *et al*, 2013

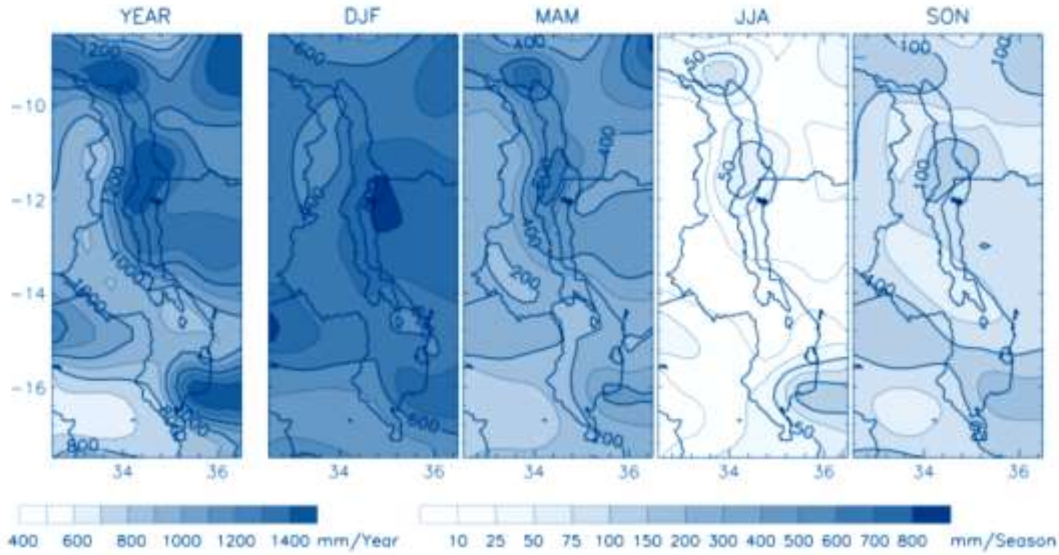

Figure 8: Mean annual and seasonal rainfall in mm based on the period 1962 – 2009
Source: Nicholson *et al*, 2013)

Table 2: Rainfall onset, end, and duration in Malawi

Region	1	1	1	1	2	2	2	2
Station	1	2	3	4	5	6	7	8
Onset	12/4	11/19	11/23	12/1	11/27	12/6	11/27	12/1
End	4/20	4/28	5/8	4/14	4/4	3/19	3/30	3/20
Duration	138	161	167	134	129	104	124	108

Region	3	3	3	3	3	3	3	4	4	4	4	4	4
Station	9	10	11	12	13	14	15	16	17	18	19	20	21
Onset	12/4	12/3	11/28	11/27	11/27	12/4	11/23	11/27	11/15	11/14	11/13	11/29	11/25
End	3/24	4/1	3/21	3/23	3/27	3/19	3/27	3/17	3/17	4/4	4/5	3/13	3/19
Duration	111	120	114	117	122	106	126	111	123	142	144	105	114

Source: Nicholson *et al*, 2013

Figures 7 and 8 demonstrate that rainfall in Malawi is concentrated in the months of December to March. In three of the four regions, maximum rainfall occurs in January. In the region along the western lakeshore, the maximum occurs in March (Figure 7).

Furthermore, Figure 8 appears to show a rainfall maximum over the lake. It should be noted that the contours over the lake were extrapolated from land-based gauge data. However, an analysis of data from satellite imagery done by Nicholson and Yin (2002) confirmed the maximum over the lake and along its western shore. This maximum appears to be related to topographic effects, as opposed to the effects of the lake itself, because the annual means for over-lake and over-land rainfall are similar. This contrasts strongly with results obtained for Lakes Victoria and Tanganyika by Nicholson and Yin (2002) where lake effects respectively enhance rainfall by 35 and 11 per cent. Due to the varied nature of the topography of the region, rainfall is mainly influenced by both orography and convection. As metioned in the preceding discussion, the Inter-Tropical Convergence Zone (ITCZ), the Zaire Air Boundary (ZAB) and Cyclones play a key role in bringing rainfall to the study area. For high-relief areas of Dzalanyama (west of Lilongwe), Dedza and areas along the lakeshore that are tangential to the direction of the south easterly wind systems, orographic rainfall is predominant while much of the flat areas in the plateau zone especially in Lilongwe, Mchinji, Dowa, Ntchisi and Kasungu, mainly experiences convectional rainfall.

As the south-easterly winds ascend the escarpment zone from the lake, they bring with them moist air which condenses over the high-relief areas, and with suitable rainfall-forming mechanisms, precipitation occurs (Kisyombe, 2014). The highest mean annual rainfall occurs in Nkhotakota District around Benga to the north-east of Lilongwe with amounts in excess of 1,500 mm per annum (Moriniere et al, 1996), which is conformity with findings by Nicholson et al (2013), but gradually decreases westwards with amounts within the range 750 – 1000 mm. Dzalanyama Range on the Mozambique Border and areas around Dedza Mountain receive a mean annual rainfall of 900 – 1,250mm (see Table 3). Heavy rainfall is also experienced around Senga Bay in Salima where annual averages may be as high as 1,000 to 1,300 mm.

Table 3: Mean Annual Rainfall at selected stations in the Central Region (1970 – 2009)

District	Station	Mean annaul rainfall (mm)
Nkhotakota	Nkhotakota Met.	1521.0
Kasungu	Kasungu Met.	772.5
Dowa	Dowa Agric.	826.9
Mchinji	Mchinji Boma	1044.4
Salima	Salima Aerodrome	1262.4
Salima	Chitala Agric.	878.4
Lilongwe	KIA Met.	849.9
Lilongwe	Chitedze Met.	898.2
Dedza	Dedza Met.	946.8
Ntcheu	Nkhande Agric.	1183.6

Source: Department of Climate Change and Meteorological Services, Blantyre

High and persistent precipitation has been noted to cause serious flooding in Malawi. In

2015, Malawi experienced record-breaking high rainfall, mostly during the first two weeks in the month of January after the onset of rains, resulting in severe flooding in 15 out of a total of 28 districts.

Generally, the Central Region is vulnerable to both floods and droughts. High intensity rainfall as pointed out above is the main cause of flooding in Malawi, and the severity of flooding is exacerbated by human settlements that have been established in the fertile flood plains, causing serious damage to property and infrastructure and loss of life. Severe flooding is frequently experienced in the river basins of Linthipe and Bua.

Nearly all droughts that have taken place in Malawi have been associated with the El Nino and Southern Oscillation (ENSO) phenomena. Recent studies about the ENSO warm phase episode in southern Africa show the existence of two drought cells both of which affect Malawi, mainly the southern part of the country (Eastman *et al*., 1996). The first drought cell shows a path originating from Namibia but covering Botswana, Zimbabwe, southern Zambia, northwest Mozambique and the southern part of Malawi.

The second drought cell has its centre located near southern Mozambique and southern Zambia and appears to expand outwards. This drought cell too affects Malawi, particularly the southern part of the country. There are no signs at the moment to suggest the abetment of these drought cells from wreaking havoc in the country as attested by climate change studies done by Chavula and Chirwa (1996). Malawi experienced worst droughts in the 1948/49 and 1991/92 seasons.

1.4 Physiography and Soils

Malawi may be divided into four major physiographic zones, namely: the high land areas, plateau areas, rift valley escarpment and rift valley plains (Water Department/UNDP, 1986) as seen in Figure 6. The plateau areas occupy approximately 75 per cent of the land surface and range from 750 – 1,300 metres in altitude while the rift valley plains comprise the flat land along Lake Malawi and range from 450 – 600 meters in altitude. The plateau areas are extensively peneplained gently undulating surfaces with broad valleys and large level areas on the interfluves. They are ancient erosional surfaces (the African surface) of late Cretaceous to Miocene age, which slope away from the escarpment zones as a result of uplift along the Rift Valley, but the drainage systems have kept pace with these earth movements and largely drain towards the rift valley to the east. As a consequence, the valleys become more incised towards the escarpment (Water Department/UNDP, 1986).

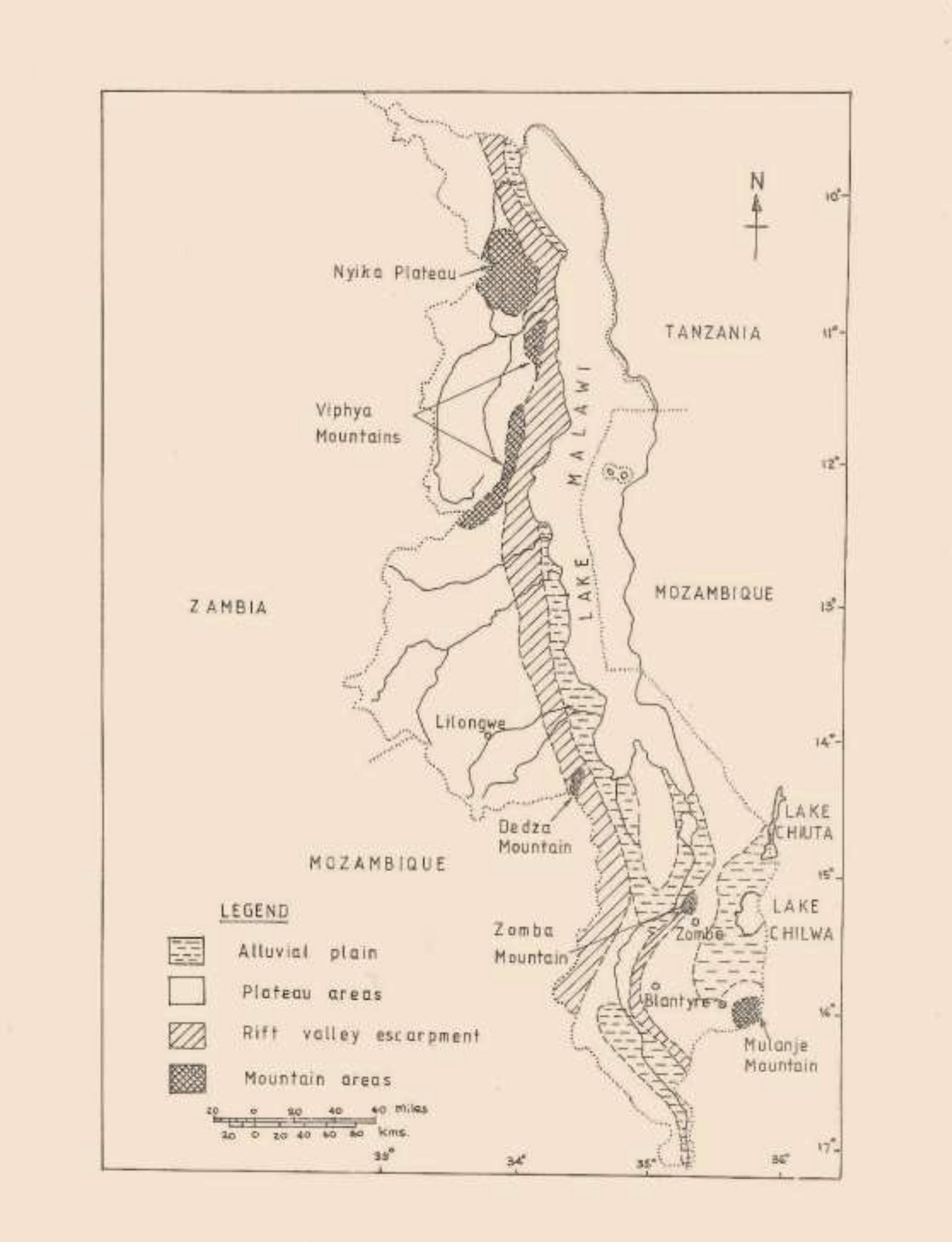

Figure 9: Physiographic features of Malawi

Source: Water Department/UNDP, 1986

The plateau areas are drained largely by dambos, i.e., broad, grass-covered swampy valleys that are liable to flooding and commonly have no well-defined channels. Soils in Malawi may generally be grouped into 13 major FAO soil groups and 33 FAO soil units, though predominated by 3 FAO major soil types (Figure 10 and Table 4):

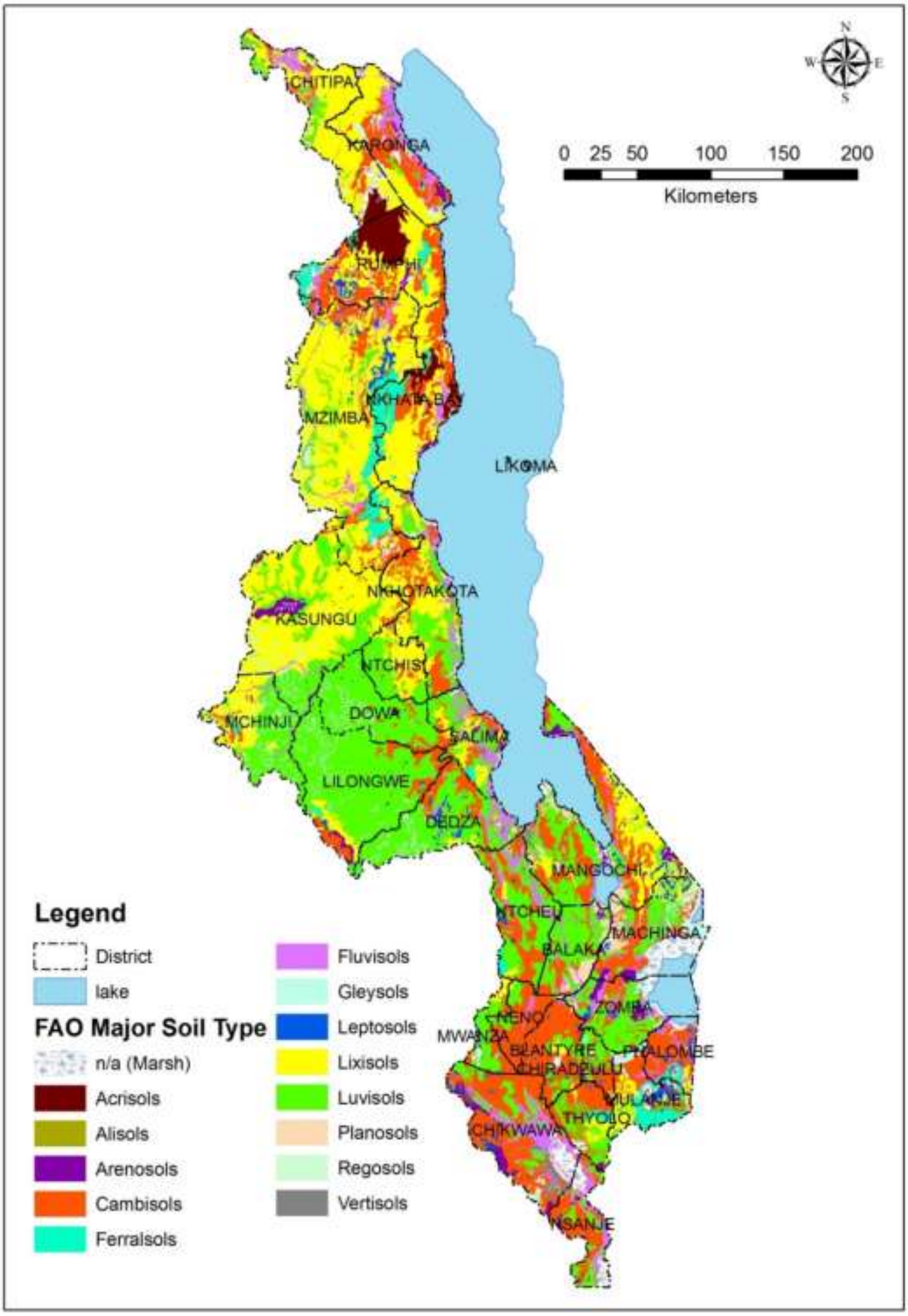

Figure 10: Soil Types of Malawi

Source: Malawi Government, 2015

Table 4: Main soil types /land types and their area distribution in Malawi

No.	Major Soil Types/Land Types	Area	
	Major Soil Types	Km^2	per cent
1	Acrisols	1,646	1.4
2	Alisols	498	0.4
3	Arenosols	1,486	1.6
4	Cambisols	20,430	17.2
5	Ferralsols	2,651	2.2
6	Fluvisols	6,138	5.2
7	Gleysols	2,576	2.2
8	Leptosols	1,727	1.5
9	Lixisols	25,885	21.8
10	Luvisols	26,544	22.4
11	Planosols	859	0.7
12	Regosols	526	0.4
13	Vertisols	477	0.4
Sub-Total Major Soil Types		***91,450***	***77.2***
	Miscellaneous		
14	Lakes /water body	22,743	19.2
15	Bad lands/marshes	4,286	3.6
16	NA	1	0.001
Sub-Total Land types		***27,029***	***22.8***
Grand Total		118 480	100

Source: Government of Malawi, 2015

(a) The Chromic Luvisols, generally known as Latosols, which are the red-yellow soils of the Lilongwe plain and some parts of southern region, 22.4 per cent;

(b) The Eutric Cambisols, which occur in most areas of the country, 17.2 per cent; and

(c) The Haplic Lixisols, which are the alluvial soils of lacustrine and riverine plains, 21.8 per cent.

Fluvisols cover some 5.2 per cent. The rest of the country is covered by the remaining 9 major FAO soil types. Table 4 summarizes the extent and distribution of the 13 major reference soil groups. The plateau areas are mostly covered by a thick mantle of saprolite derived by in-situ weathering of the underlying strata. The predominant soils covering the plateau and lakeshore areas are deep, calcimorphic alluvials and colluvials, with hydromorphic soil deposits found in isolated depressions.

1.5 Geology

Geologically, most of the area in the Central Region is underlain by crystalline metamorphic and igneous rocks of Pre-Cambrian to Lower Palaeozoic age commonly referred to as the Pre-Cambrian Basement Complex (Figure 11a and 11b). These rocks are overlain by younger sedimentary and volcanic rocks.

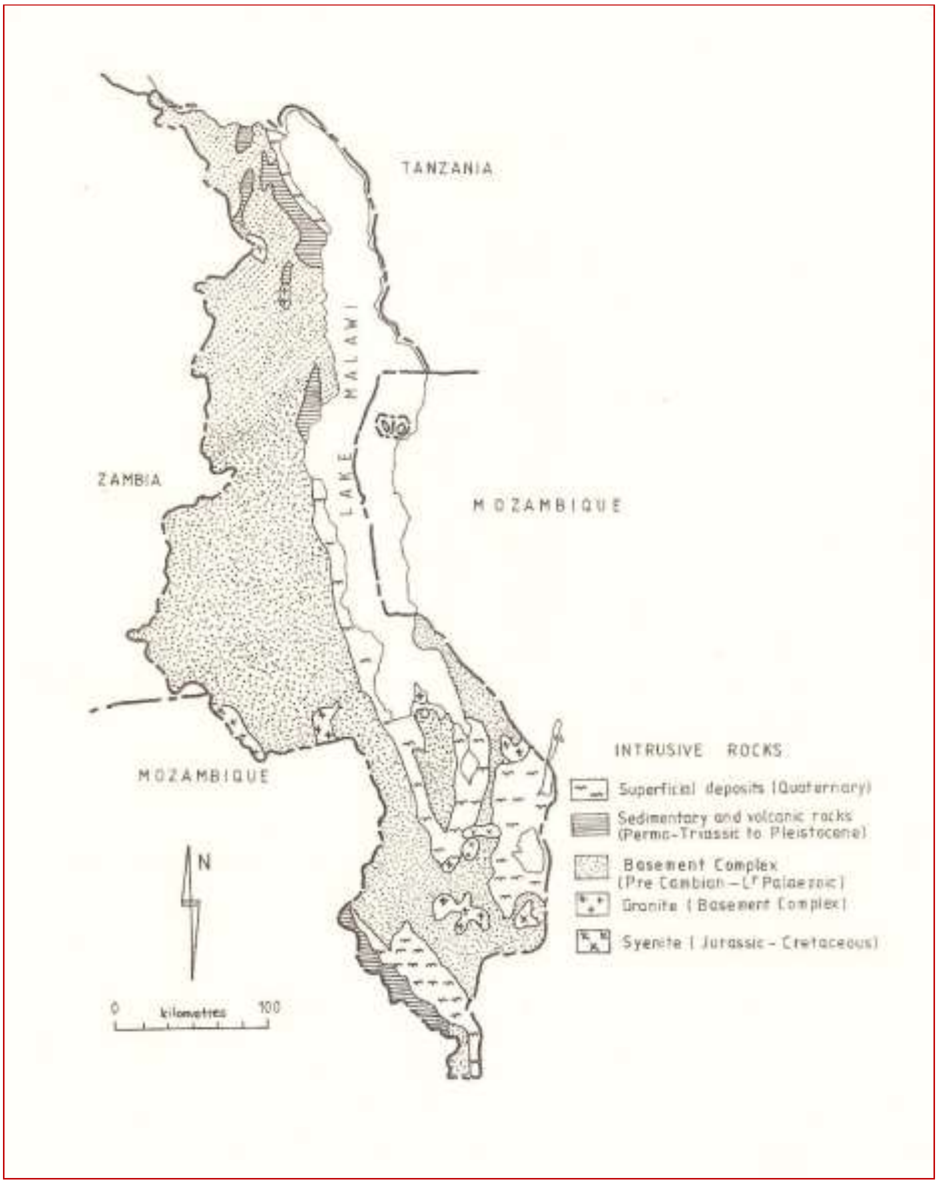

Figure 11a: The general geology of Malawi

Source: Water Dept/UNDP, 1986

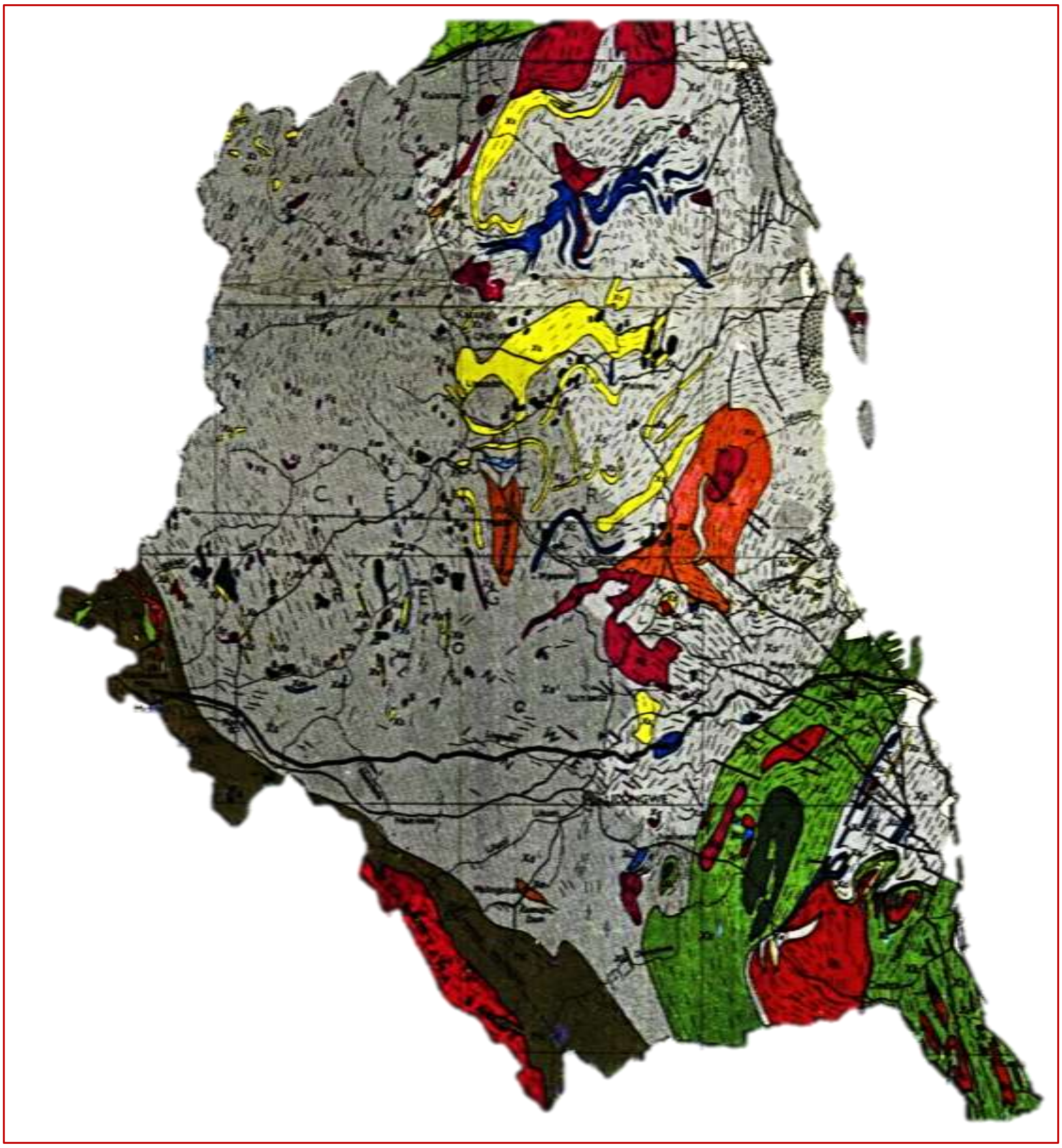

Figure 11b: Geology of the Central Region of Malawi

Source: GoM, 1971

Key to the geological map on the previous page

	Alluvium
	Thick residual soils and colluvium superimposed on formational colour)
	Dwangwa Gravel: residual pebble sheets
T	Sungwa, Chiwondo and Chitimwe Beds:pebbly sandstones, conglomerates, marls, sands and gravels
C	Dinosaur Beds(C)and Lupata Series(C_L):calcareous pebbly sandstones
K	Karroo System: sandstones, calcareous mudstones and carbonaceous shales
N	NachipereSeries; conglomerates, arkoses and carbonaceous shales
M	Mafingi(Ma) and Mchinji(Mc) Groups:psammites and pelites
Xg	Granitoid and pegmatoid gneiss
Xne/Xae	Nepheline(ne)- and aegirine(ae)- gneiss
Xc	Marbles and calc-sillicate granulites
Xs	Psammites:quartzites and quartzofeldspathic granulites
Xa	Pelites:mica-schists, kyanite and sillimanite schists and gneisses
Xa'	Semi-pelitic rocks:biotite- and hornblende-gneisses, commonly garnetiferous and locally graphitic
Xk	Charnockitic suite: banded pyroxene-granulites and gneisses, hypersthene-granite
X	Undifferentiated paragneisses, schists and granulites

Along the shore of Lake Malawi, the bedrock is covered by unconsolidated Quaternary alluvium. The Basement Complex rocks have been subjected to several phases of deformation and metamorphism affecting large tracts of Africa. Biotite and hornblende gneisses are most commonly encountered, although other rock types are often inter-banded with them.

Apart from the Basement Complex rocks, other rock types commonly found in the region include the Karoo Sedimentary Series, the Karoo Stormberg Volcanics, the Cretaceous to Pleistocene sediments, and Quaternary alluvium. The Karoo sedimentary series lie on, or are faulted against the underlying Basement Complex. The Karoo sediments are well cemented by calcite and indurated; the primary porosity is thus low. The Stormberg Volcanics represent the upper part of the Karoo system. They comprise a series of basaltic lava flows with occasional thin bands of tuff and sandstone (Agnew and Stubbs, 1972). The Cretaceous to Pleistocene sediments consist of friable sandstones, unconsolidated sands, sandy marls, clays, and conglomerates. The Quaternary alluvium rocks comprise both lacustrine and riverine colluvial and fluvial deposits. The deposits are unconsolidated and have been formed by deposition from rivers debouching from the rift escarpment and along the lake shore, also from lacustrine sedimentation.

Along the lakeshore from Mtakataka in the south to Dwambazi in the north are found alluvials interspaced by biotite and hornblende gneisses and graphites on the Escarpment Zone above Chipoka, banded pyroxene granulites and gneisses and hypersthene granites that underlie much of the region surrounding the mouth of the Linthipe River below the Escarpment Zone.

Pockets of residual pebble sheets (also known as Dwangwa gravel) are found along the rivers of Lingadzi and Chirua as they enter the Lakeshore Plain and from Chia Lagoon to the headwaters of the Lifuliza. These soils are also found at Dwangwa. The alluvial soils of the lakeshore plain are distinctly alienated from the Escarpment Zone by topography (Malawi Government, 1971). The geology of a particular river basin will therefore determine the dominance of a particular soil type in that area. In the case of the lakeshore plain for instance the dominance of alluvial soils could lead to excessive scour and erosion during floods and flooding as will be shown later in this study.

1.6 Vegetation Cover and Land Use

Desanker and Frost (1999) divided Malawi into 11 land cover classes (Table 5), namely: natural forest, forest plantation, woodland, bushland/scrubland, wooded grassland, grassland, barren ground, water, swamp/marsh, cultivation, and built up area. Kainja (2000) identified five classes of forests (Table 6), namely: Forest Reserves, National Parks and Game Reserves, Government Plantations, Private Plantations, and Forests on Customary Land.

Forest Reserves fall under the responsibility of the Department of Forestry and are conserved to protect hills and mountains and other fragile areas. National Parks and Game Reserves are managed by the government for the preservation of wildlife. Customary Land Forests are owned by small-scale farmers. Plantation Forests, comprising exotics such as *Pinus patula* and *Eucalyptus*, are managed by the Department of Forestry. Private Plantations are owned mostly by tea and tobacco estates.

Table 5: Land cover types of Malawi

Land Cover Type	Area Coverage (km^2)	Area Coverage (per cent) of total
Natural forest	828	0.69
Forest plantation	1,418	1.18
Woodland	25,357	21.19
Bushland / Scrubland	0	0
Wooded grassland	394	0.33
Grassland	7,071	5.91
Barren ground	0	0
Water	24,430	20.41
Swamp / Marsh	1,733	1.45
Cultivation	58,215	48.65
Built-up area	225	0.91

Source: Desanker and Frost, 1999

Table 6: Forest distribution in Malawi

Forest Category	Areal Coverage (ha)	per cent of total forest cover
Forest Reserves	870,052	22
National Parks and Game Reserves	981,479	25
Government Plantations	90,000	2
Private Plantations	20,000	1
Customary Land	1,988,255	50
Grand Total	**3,949,786**	**100**

Source: Kainja, 2000

The natural vegetation cover over most of the Central Region is "miombo" (Brachystegia) deciduous woodland, but this wood resource is under severe pressure for domestic uses because of the fuelwood demands, expansion of agriculture production exacerbated by increases in population growth (Figure 4 and Table 1). The indigenous tree species are present in the forests and woodland areas covering much of Nkhotakota (Nkhotakota Forest Reserve), Kasungu (Kasungu National Park), Mchinji (Mchinji Forest Reserve) Dowa (Ngara Mountain, Kongwe Hill and Dowa Hills) and Lilongwe (Dzalanyama Forest Reserve). Other land use classifications include marshes mainly surrounding wetlands such as Chia Lagoon and along the littoral of the lake. Roads, tracks and other communication routes also take their share in land use within the region.

All rural households in the region use wood for cooking while 90 per cent of urban households use charcoal. The twin catchment pressures of agriculture and biofuel essential to survival have led to high rates of forest loss with substantial consequences for the water quality and quantity as well as increasingly erratic river flows (Hecky et al 2003).

Chavula (2008) conducted a study on the variation in spatial distribution of four land-use classes in the Lake Malawi Basin, which includes the Central Region, over the period 1982 – 2005, namely: savanna/shrub/woodland, forest, cropland, and water bodies using Advanced Very High Resolution Radiometer (AVHRR) and Moderate Resolution Imaging Spectroradiometer (MODIS) satellite imagery. The corresponding information on areal extent for each of the four classes was presented in tabular form and into land use and land cover (LULC) maps. Maps produced from AVHRR-NDVI data sets had 8-km resolution whereas LULC classification maps were constructed from 500-m resolution Terra/MODIS-NDVI data.

The findings showed that marked differences exist between areal coverage of LULC by the two sensors in regard to cropland and savanna/shrub/woodland. AVHRR data showed an increase in land cover for cropland from 1982 – 1990, followed by a slight decline in 1995. MODIS showed a decline in land cover under crops from 2001 to 2005. AVHRR data showed a decline in savanna/shrub/woodland from 1982 to 1995, whereas MODIS data showed an increase in areal coverage from 2001 to 2005.

The results showed that it was not forests that suffered serious depletion in the Lake Malawi Basin with increased agricultural production and the resultant expansion in the cropland area, but savanna/shrubs/woodland. These findings contrast results obtained by Calder *et al*. (1995) in their model simulation study, in which they concluded that forest depletion in the basin of Lake Malawi caused an increase in lake level.

Land cover within the region is directly related to population density and settlements. It is understood that although the national population growth rate declined to 2 per cent per annum during the period 1987 – 1998 from 3.7 per cent during the previous decade, high population density and poverty in many parts of the country were contributing to pressure on natural resources (Malawi Government, 2010) and having direct link therefore on land cover.

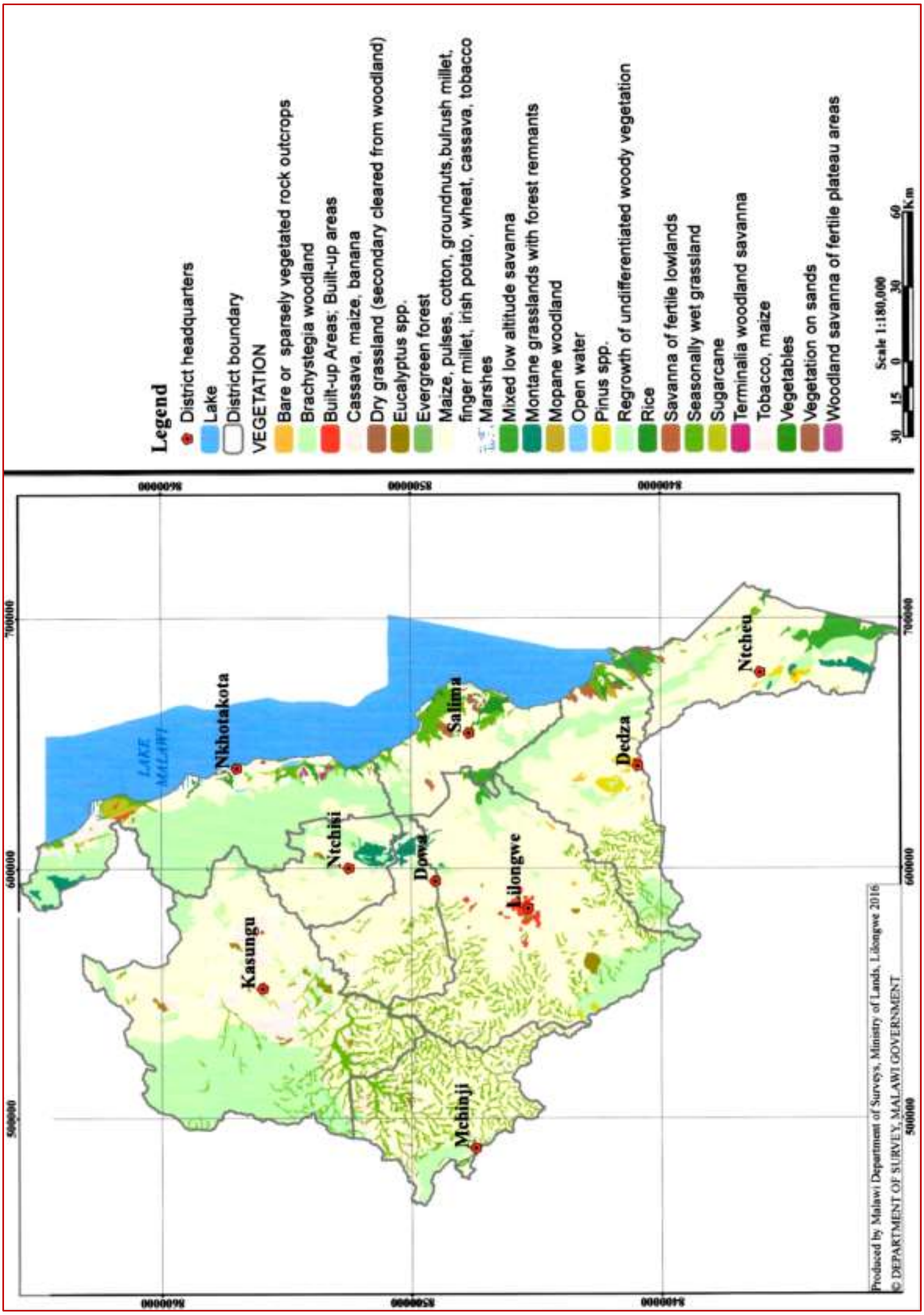

Figure 12: Land cover in the Central Region of Malawi

Source: Department of Surveys, Lilongwe

As will be seen from Figure 12 much of the region consists of non-forest areas and open forest limiting closed forests to those areas only gazetted by government. The following forest areas form the main areas with significant land cover in the region. All the districts therefore have some areas reserved for forests as seen in Table 7.

Table 7: Gazetted Forest Reserves as of May 2014

No.	Forest Name	District	Area (km^2)	Year Gazetted
1.	Chongoni	Dedza	126.4	1924
2.	Dedza Mountain	Dedza	32.6	1926
3.	Dzenza	Dedza	8.3	1948
4.	Msitolengwe	Dedza	0.6	1974
5.	Dedza-Salima Escarpment	Dedza/Salima	326.0	1974
6.	Mua-Livulezi	Dedza/Salima	121.5	1924
7.	Mua-Tsanya	Dedza/Salima	10.6	1932
8.	Dowa Hills	Dowa	24.2	1974
9.	Kongwe	Dowa	18.1	1926
10.	Ngara	Dowa	22.5	1958
11.	Chimaliro	Kasungu/Mzimba	161.0	1926
12.	Dwambazi	Nkhotakota/ Nkhata Bay	763.0	1996
13.	Dzalanyama	Lilongwe	989.0	1922
14.	Nalikule	Lilongwe	1.0	1948
15.	Thuma	Lilongwe/Salima	164.0	1926
16.	Mchinji	Mchinji	192.0	1924
17.	Kaombe	Ntchisi	38.9	1992
18.	Ntchisi Mountain	Ntchisi	97.1	1924
19.	Mdirasadzu	Ntchisi	155.0	1974
20.	Malere Island	Salima	2.1	1930
21.	Senga Hills	Salima	16.9	1958

Source: Malawi Government, 2010

Table 7 illustrates an important policy provision which was enacted and enforced even before the country got its independence in 1964 which is to say that already 1,963.1 km^2 had been declared as protected areas. Only six other areas have since been declared forest reserves in the Central Region since independence in 1964 as can be seen from Table 7. As will be apparent from Figure 13, the major forest reserves within the region are, Chongoni, Dedza/Salima, Mua/Livulezi, Chimaliro, Dwambazi, Dzalanyama, Thuma, Mchinji and Mdirasadzu. All the nine forest reserves are mountainous area that are rugged and not suitable for settlement and cultivation but they are also important, being the sources of some of the rivers in the region.

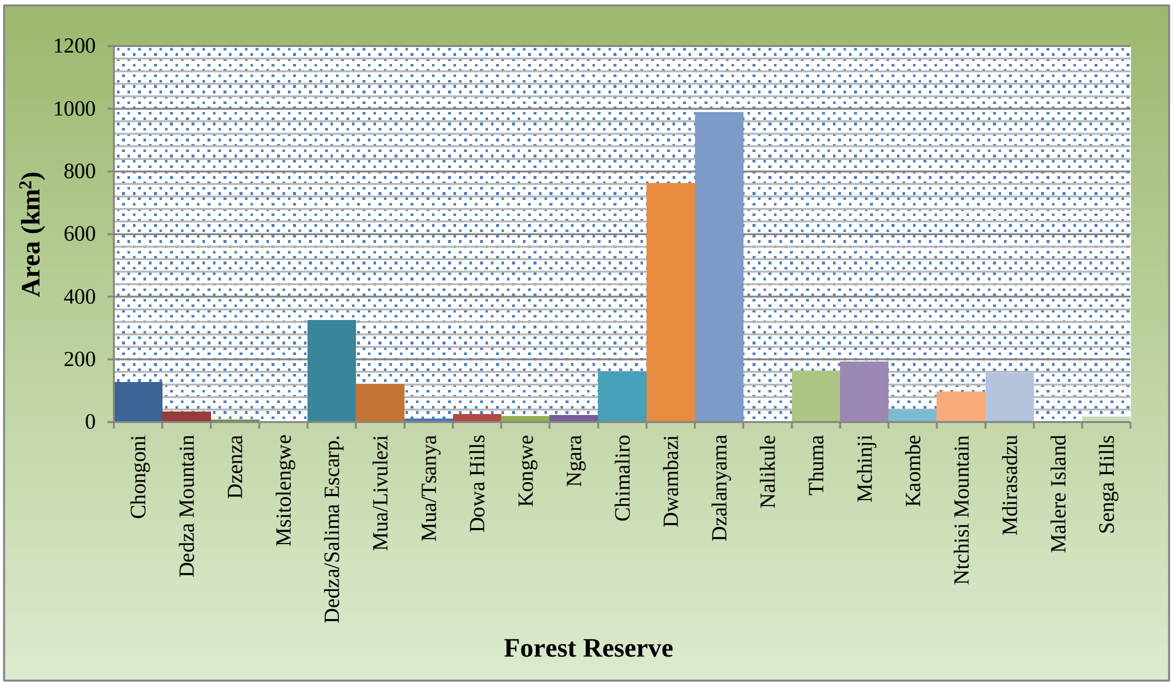

Figure 13: Forest cover in the Central Region of Malawi

Source: Produced from data in Table 7

Land cover within the region is directly related to population density and settlements. It is understood that although the national population growth rate declined to 2 per cent per annum during the period 1987 – 1998 from 3.7 per cent during the previous decade, high population density and poverty in many parts of the country were contributing to pressure on natural resources (Malawi Government, 2010) and having direct link therefore on land cover.

1.7 Hydrology

A detailed discussion on the hydrology of Lake Malawi Basin, which includes the Central Region, was given by Shela (2000). The drainage system of the region comprises the following main rivers: Linthipe, Bua, Dwangwa, and Dwambazi. As pointed out in the preceding discussion, the rainy season in the Central Region commences in November and ends in April the following year. Both the land catchment and the lake rainfall peak up in March.

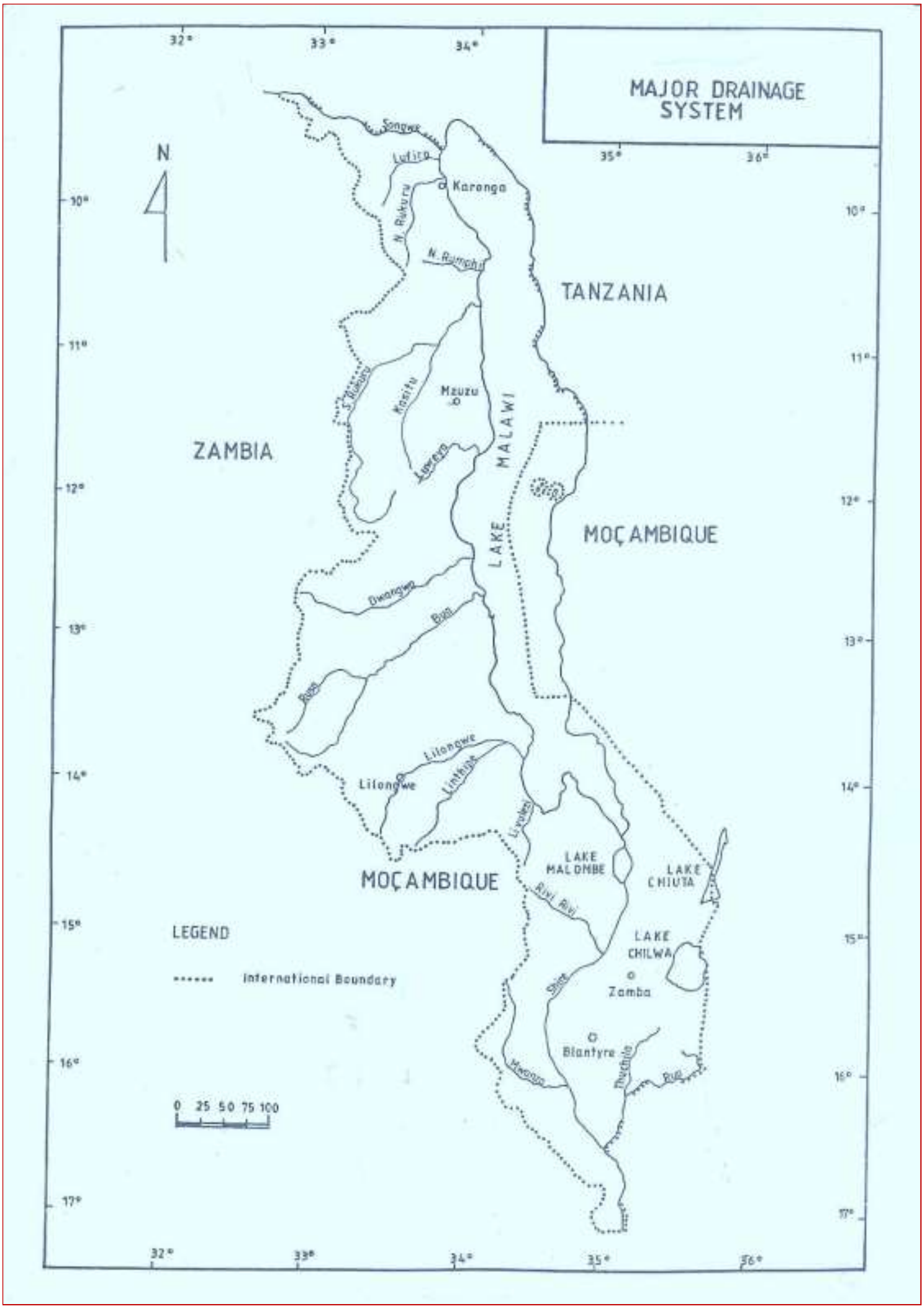

Figure 14: Major Drainage Basins of Malawi

Source: Water Department/UNDP, 1986

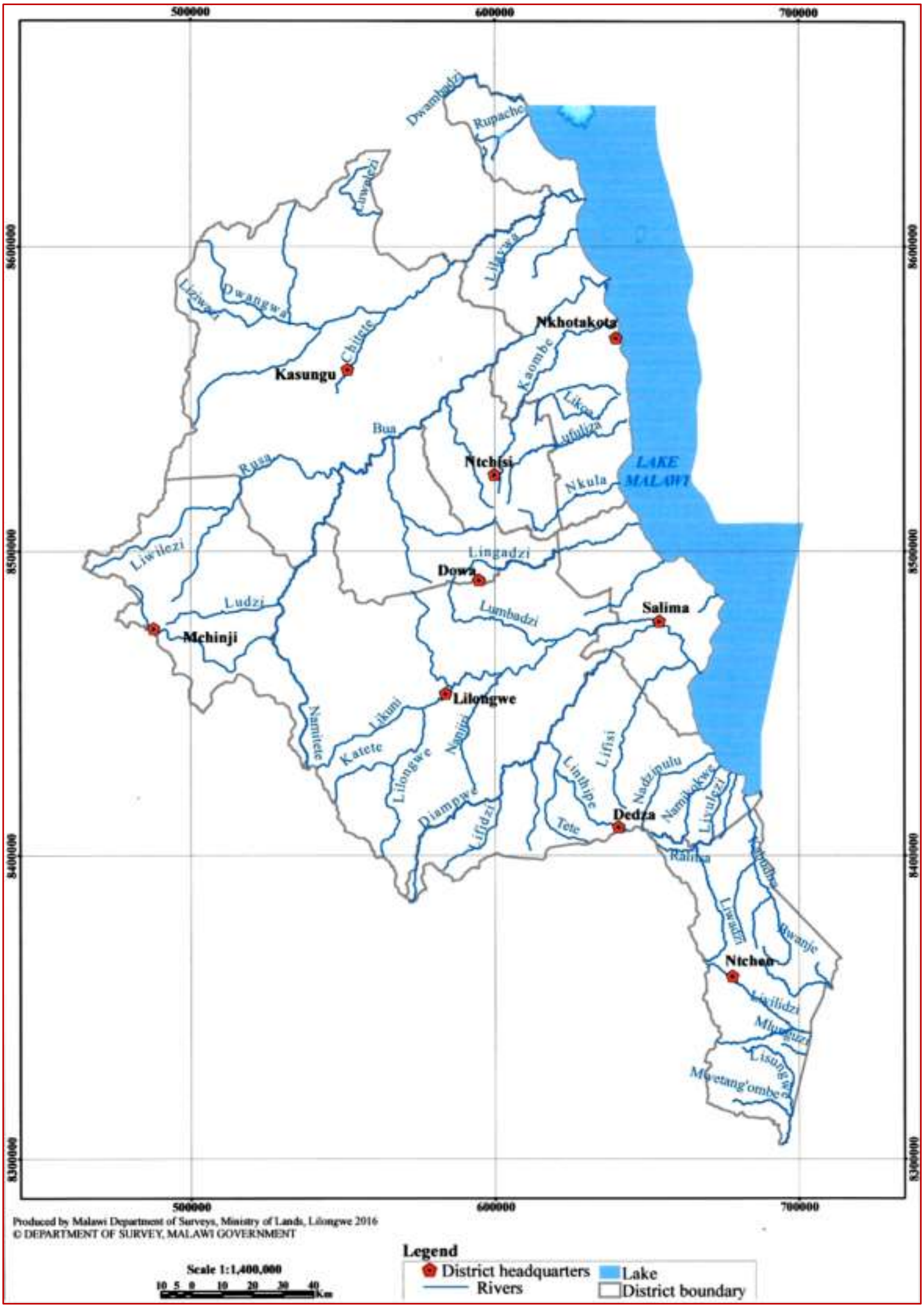

Figure 15: Major Rivers of the Central Region of Malawi

Source: Department of Surveys, Lilongwe

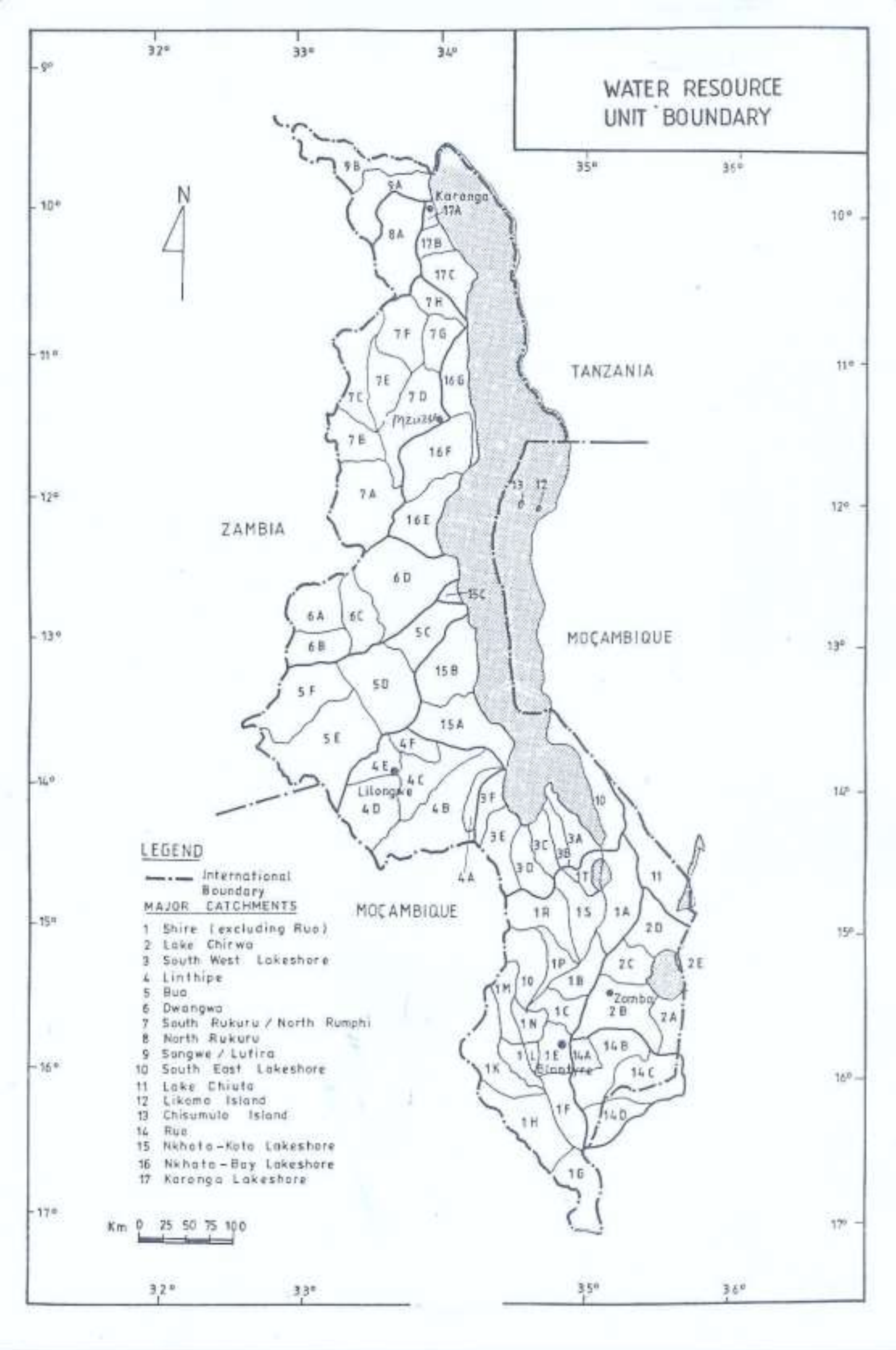

Figure 16: Water Resources Units

Source: Water Department/UNDP, 1986

The country's Water Resources Units (WRUs) and the Water Resources Areas (WRAs) of the Central Region are presented in Figure 16 and Table 8 respectively.

The country's river basins show that apart from the Shire and the South Rukuru, the Central Region has the largest river basins, with a combined catchment area of 26,280km^2. Other river basins such as the South-Western Lakeshore and Nkhotakota Lakeshore take the eigth and nineth positions respectively among the 17 WRA in the country in terms of size (refer to Figure 17).

Table 8: Water Resources Areas and Water Resources Units of the Central Region

Water Resources Area (WRA)	Water Resources Units (WRUs)	Name (s) of river basin (s)
3 South-Western Lakehore	D	Bwanje
	E	Namikokwe
	F	Nadzipulu
4 Linthipe	A	Lifisi
	B	Linthipe and Diamphwe
	C	Lilongwe, Nanjiri and Nathenje
	D	Lilongwe, Likuni
	E	Lingadzi
	F	Lumbadzi
5 Bua	C	Bua Lower
	D	Bua, Mtiti
	E	Bua, Namitete
	F	Rusa, Liwelezi
6 Dwangwa	A	Dwangwa, Liziwazi, Mpangala
	B	Lingadzi
	C	Mpasadzi, Chitete
	D	Milenje, Liwelezi, Rupache, Dwangwa Lower
15 Nkhotakota Lakeshore	A	Lipimbi, Lingadzi, Chirua
	B	Nkula, Lifuliza, Likoa, Kaombe

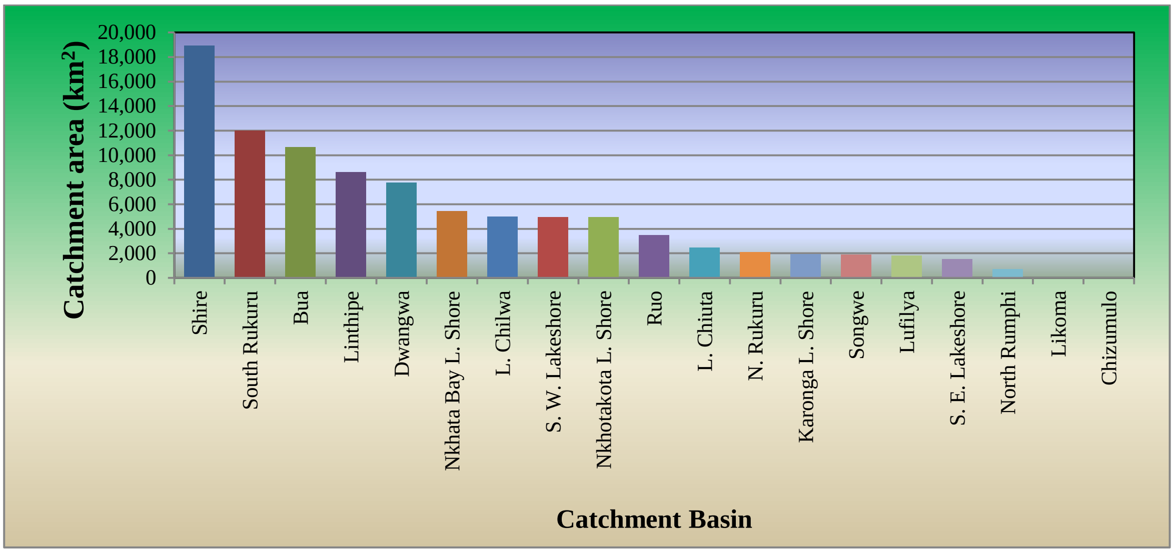

Figure 17: River Basins of Malawi and their respective areas

Source: Produced from data from the Department of Water Resources, Lilongwe

1.7.1 South-Western Lakeshore

The rivers under study and which fall within this river basin constitute those that drain the Dedza Mountain and sourrounding areas and empty their waters into the south-western arm of Lake Malawi. These rivers include the Livulezi, Nadzipulu and Namikokwe. All the three rivers traverse a relatively well vegetated area which is protected over the highlands by vegetation even though signs of extensive subsistence cultivation are evident in their respective headwaters. The rivers have steep gradients as they flow through the Escarpment Zone with high velocities and abruptly become sluggish upon entry into the Lakehore Plain around Golomoti, Mua and Chipoka respectively. Here, the flow may even disappear into the loose sands that cover much of the lakeshore plain (Kaluwa, undated).

1.7.2 Linthipe

The Linthipe River flows from the south-western corner of the region on the Malawi-Mozambique frontier and is joined by the Diamphwe, Lilongwe and many other rivers and streams before emptying its waters into Lake Malawi at Salima. In its mature stage, the river enters a flat and swampy area where flow velocities are inhibited by the gradient and aquatic vegetation and flows sluggishly towards the lake, inundating large areas in the process particularly during years of heavy rainfall. The drainage of the Central Region is presented in Figure 4. In its upper and middle reaches, its tributaries consist of *dambos*, i.e., wet flat valleys which act as a sponge and gradually release water to the river channel. The structure of a dambo can best be destcribed by its relief, the underlying material, soils, hydrology and rainfall as well as by vegetation (See Box 1).

Box 1: Structure of Dambos

Drainage

Headwater dambos – These have no defined channels, are broad and in some cases may join to form a large dambo. This group is particularly common in highland plateaux.

River or stream dambos – These typically occur adjacent to second or third order rivers and streams.

Residual dambos – These are narrow and linear concavities, predominantly in first order streams.

Seasonality

Some dambos may be permanent due to continuous flow or seepage, while others are seasonal in nature where wetness may continue for a considerable length of time, but may not be permanently sustained. Dambos formed by virtue of a perched water table are usually considered seasonal.

Vegetation

Sour dambos: These occur in high-rainfall areas and are dominated by plant species such as *Loudetia simplex, Trachypogon spicatus, Imperata cylindrica, Aristida* sp., *Eragrostis* sp., *Andropogon* sp., and a large number of sedge species. Tree species incluse *Vitex* sp., and *Syzygium* sp.

Sweet dambos: These usually occur in low-rainfall areas and are predominantly covered by plant species such as *Echinochloa pyramidalis, Setaria* sp., *Acroceras macrum, Leersia hexandra, Acacia polyacantha, Acacia nilotica, Acacia albida* and *Piliostigma thonningii*.

Source: Breen C. M. et al. (1997) page 14

1.7.3 Bua

The Bua River flows from the Dzalanyama Range on the Malawi-Mozambique border with its major tributary, the Rusa, draining the eastern slopes of the Mchinji Mountains on the Malawi-Zambia border. The Bua River flows through a relatively flat gradient covering the districts of Lilongwe, Mchinji, Dowa, Ntchisi, Kasungu and to a lesser extent, Nkhotakota where it empties its waters into Lake Malawi. Much of the upper and middle stages of the Bua River Basin are covered by three categories of *dambos:* residual, river and headwater *dambos* but headwater *dambos* predominate. These *dambos* may be classified as sweet *dambos* as defined by Breen et al. (1997) since they occur in areas of relatively low rainfall where the mean annual rainfall is to a greater extent below 1,000mm.

1.7.4 Dwangwa

Much of the upper basin of the Dwangwa lies in the Kasungu National Park where the mean annual rainfall is less than 700mm. The majority of its major tributaries such as Liziwazi, Mpangala, Lingadzi and Mpasadzi have their sources in this part of the basin. However, despite being dry in the upper reaches, the Dwangwa River Basin still enjoys adequate rainfall as it flows eastwards towards the lake where the mean annual rainfall steeply increases from 700 mm to over 1,300 mm (Majamanda et al, 2005) recorded at Dwangwa Trading Centre on the Nkhotakota – Nkhata Bay Lakeshore Road.

1.7.5 Nkhotakota Lakeshore

River basins of this WRA consist of rivers that mainly rise from the top of the Escarpment Zone and they flow swiftly till they reach the Lakeshore Plain after which the velocity of flow dramatically get reduced by the flat topography prevalent in the area. This catchment area is very similar to South-Western Lakehore except that it is longitudinal and runs parallel to the lake’s littoral zone (Malawi Government, 1986c). Although the catchment partly consists of thick vegetation cover, it predominantly consists of scanty vegetation in parts and is heavily cultivated by local communities who have settled in the area. Major rivers that drain the catchment include the Lipimbi, Lingadzi, Chirua, Nkula, Luwazi, Lifuliza, Likoa and the Kaombe. The majority of these rivers are non-perennial.

1.8 Objectives of the Study

The main aim of this study was to develop a flood frequency model for the Central

Region by specifically undertaking the following activities, namely, by:

(a) Documenting flood occurrences in the Central Region;
(b) Examining flood frequency models developed elsewhere and in Malawi; and
(c) Developing a flood frequency model specifically for the Central Region of Malawi.

These specific objectives are elaborated in much detail in Section 2.4 and are followed by a conclusion.

1.8.1 Research Questions

In order to address specific objectives lighted above, the following research questions guided the investigation:

(a) Where have floods occurred in the Central Region and what has been their impact?
(b) Can flood frequency models developed outside Malawi be relevant to the Central Region?
(c) Is it possible to develop a flood frequency model specifically for the Central Region of Malawi?

1.8.2 Rationale of the Study

Floods of varying frequencies and magnitudes have been experienced in many parts of the country, causing the displacement of people, destruction of infrastructure and damage to crops (ACT Alliance, 2015; PANA, 2003; WHO, 2003; Davies, 2015). Although floods in Malawi are rampant in the southern districts of Chikwawa and Nsanje in the Lower Shire Valley (Mtilatira, 2007), they have also been noted to significantly affect other districts in the Northern and Central Regions of the country (UNICEF, 2014) causing loss of life and damage to property, particularly public infrastructure such as roads and bridges.

With further modification of the landscape through changes in land use, floods will continue to occur in flood-prone areas of the Central Region with varying degrees of frequency and magnitude. To date no regional frequency analysis model has been developed for the Central Region. Thus, this study was intended to fill that knowledge gap.

1.8.3 Significance of this Study

The need to lessen the severity of flood disasters cannot be overemphasized. The Southern African Development Community recognises the importance of water resources assessment and research and attributes this responsibility to the citizens of the community to carry out strategic environmental and risk assessments (SADC, 2005). It is the intention of this study therefore to contribute towards government's efforts to reduce the suffering of its people and damage to infrastructure caused by flood hazards by developing a regional flood frequency model for use in designing engineering structures and in the planning of the location of settlements in areas traversed by rivers.

CHAPTER 2
LITERATURE REVIEW

2. Introduction

The chapter focuses mainly on the two aspects of flood frequency models developed in Malawi and in other countries, and further compares model results for river basins in the Central Region. The chapter concludes by showing that due to heterogeneity of river basins, no one formula on flood frequency analysis can be applied to all river basins in a country or region, and therefore it is necessary that boundaries be drawn defining a homogeneous region for which such a flood formula could be developed using historical data.

2.1 Examination of Flood Frequency Models

The University Corporation of Atmospheric Research (UCAR) at Colorado (2006) stated that flood frequency analysis provides guidance on the manner of future floods and flooding, i.e., it is used in predicting the severity of a future flood at a given return period. Noting the unpredictable flood events that Malawi experiences, it is an absolute necessity that a flood frequency model should be developed for the Central Region as a tool for predicting future flood events and their associated magnitudes and return periods.

Generally, design engineers face serious challenges in estimating floods of a given frequency and magnitude in ungauged catchments in Malawi because the available estimation methods yield varied results. Thus, it becomes difficult to decide which of the methods to choose for a particular task. In addition, all the available methods for estimating flood frequency and magnitude so far developed for use in Malawi have not considered homogeneity of the hydrological basins as an important factor in determining the characteristics of the basins under consideration.

In light of the above, the credibility of the flood frequency models developed may be compromised by this omission. Some of the existing models that apply to Malawi either consider the whole country as one homogeneous region (Drayton et al. 1980; Krishnamurthy, 1987) or the model covers the whole of southern Africa (UNESCO, 1997; Mkhandi, 1996) or homogeneity of the river basins is based on topography (Pike, 1971).

A regional flood frequency model is a necessary tool for determining the extent to which flooding within river basins will take place, and therefore using the same tool in the design of hydraulic structures and floodplain management (Michna, 2015) has great potential in developing hydraulic structures that will lessen flood damage. Such a tool can also be used in the production of flood zoning maps whereby areas unsuitable for human settlements and agricultural production could be delineated and declared flood prone areas.

In examining flood frequency models, the study considered models developed for Malawi Malawi and those developed for other countries. Differences occur from country to country and from region to another in terms of topography, climate, drainage, geology, soils and other parameters critical in the development of flood frequency models, and for this reason (Goel, et al. 1999) no one flood frequency model is applicable to all the countries or regions. This is why it becomes necessary to develop a specific regional model that is applicable to a homogeneous region and therefore the need for conducting a homogeneity test. And this is the approach that was taken in this study in developing the flood frequency model for the Central Region.

2.2 Some Empirical Flood Formulae Developed Outside Malawi

Regional flood frequency models are not new for they have been developed before in other parts of the world. The simplest of these is the empirical method which is of the form:

$$Q = CA^n$$

Where Q is the flood magnitude in m^3/s;
A is the basin area in km^2;
C is the drainage coefficient; and
n is an appropriate basin coefficient calculated for a particular region.

This simple model was first developed and used by Dickens in India (Wilson, 1974). Another method that has been used for estimating flood flows is the Rational Method which is characterised by the equation given below (Viessman *et al.*, 1972):

$$Q = CIA$$

Where Q is the flood magnitude in m^3/s;

A is the drainage area in km^2;

C is the runoff coefficient; and

I is the rainfall intensity in mm/hour.

However, the use of this method requires appropriate apportioning of the storm intensity from the eye of the storm to its boundary, as intensity is not evenly distributed from the storm, particularly the eye (Gray, et al. 1973). The use of the method for larger catchments becomes problematic when a huge storm in one corner of the basin can produce a huge flood in the lower reaches of the basin when other parts of the catchment are relatively dry. Further, the Rational Method cannot quantify the magnitude of a flood that can be expected in 5, 10, 25, 50 or more years since this simple model has not time into consideration.

Regional flood frequency models therefore take into account the physical characteristics of an area and are not transferable from one region to another. In India for instance other models have been developed for specific regions which relate to climatic conditions of those areas, their geology, soils, slope of the basins, land use, shape of the catchment and so on (Srinivas, 2012).

2.3 Factors that Influence Basin Flow

Some of the factors that influence basin flow are described below:

<u>Rainfall intensity</u>

The amount of precipitation received within a river basin is important in determining the flow within the main channel. In this regard, the time and intensity of the storm will determine how much water is received within the basin and how it can be conveyed downstream. A high-intensity storm of short duration may produce a flash flood (University of Reading, undated) depending on the moisture content of the soil while a low-intensity storm would take some time to peak.

<u>Land gradient</u>

The general slope of the basin from the upper point of occurrence of the storm to its lower boundary is important. Indeed, the gradient from the point of occurrence of the storm and the mouth of the river will influence flow (Nelson, 2012), dictated by gravity and channel friction. In areas where the channel flows through flat land, it is almost always possible for the flow to break banks and inundate the valley. Under such circumstances, it is not possible to measure the whole flow as some of it flows spilles over the river channel. Such are cases where floods of given magnitudes have been “lost” because they could not be measured.

Land cover

Vegetation plays an important role in regulating water movement during and after precipitation. When rainfall occurs, some of the water is intercepted by vegetation thereby increasing the time the water moves from the top of the canopy to the ground. At the ground surface, a considerable amount of time is also required for the soil to absorb the water; and when the soil moiture reaches its point of saturation, runoff commences. Because of the delayed response of the soil to absorb the water, some of it infiltrates and percolates into the lower strata thereby denying much runoff to occur downstream.

Figure 18: Land cover such as this in Chitipa District, reduces runoff

Source: Elton Laisi (2010)

However, in a larger part of the Central Region where vegetation has been removed, it is clear that a small storm can generate runoff within a short period of time, with most of the rivers and *dambos* being under flooding conditions. Continued removal of forests within the region puts people and infastructure at great risk from flooding because there is no natural mechanism to facilitate infiltration and percolation of water resulting from storms. Thus, land cover plays an important role in regulating overland flows, and that the removal of vegetation can trigger exceedingly high flows resulting in severe floods in many areas as has been observed elsewhere (Fitzpatrick, et al., 1999).

Land use

Land use is another important determing factor in how floods and flooding could occur within a given area (European Commission, 2013). In heavily built-up areas with concrete pavements, drains and an umbrella of roofings, water quickly finds its way to streams and rivers, quickly reacheing concentration. The rising limb of the hydrograph is sharp and could reach the apex within an hour depending on the rainfall intensity.

In rural areas, the defining factors for flood generation are open areas consisting of settlements, farms and gardens and how farmers align their ridges on the hill slopes. Farm or garden ridges that follow the contour assist in prohibiting flow and water will be held back between ridges for some time thereby allowing for infiltration into the soil. In the case where the ridges are nearly following the direction of the slope, there is fast movement of water to the foot of the slope and the water finds its way towards the streams and rivers down below. Under such circumstances, erosion is common and leads to high river turbidity, high concentration of suspended solids including sand and silt. Land use practices such as contour ploughing are therefore important in controlling flooding (FAO, 2015).

The role that vegetation plays in moderating or controlling floods and flooding within river basins is critical. In Malawi, the implementation of a development project such as construction of a rural growth centre, development of a mine or construction of a new road can lead to the birth of “trade and commerce” between those engaged on the new development project and local communities.

Figure 19: Deforestation in one of the districts in Malawi during new road construction

Source: Elton Laisi (2010)

Figure 19 shows one such case in Malawi where during the construction of a new road between the two northern districts of Chitipa and Karonga led to plundering of the forest products by local communities for sale and a new market had also sprouted on the border of the two districts when the Kayelekera mine was opened in the same area.

Poverty is common among many rural households, and as a result, it is expected that the existence of any "opportunity" to use local resources for the generation of household income leads to more unsustainable use of local resources. Trees are cut for sale when demand for fire wood or charcoal is created. In 2014, the rampant cutting down of trees in Chitipa made the President of Malawi to intervene (Malawi News Agency, 2014). The removal of indigenous tree species from existing forests would lead to more flooding within the river basins such as those in the Central Region.

Drainage density, slope and soils

The drainage density (Pallard, et al. 2009), slope of the basin and the basin's soil type(s) are also important factors that determine levels of flooding within the catchment area. The number of tributaries leading to the main channel influences how fast runoff can be accumulated to force a rise in the stage of the main channel. The fewer the number of tributaries, the slower is the rate of flow to the main channel.

The slope of the basin is equally important because it determines how fast water can be removed from a particular point (NIWA, 2013). A channel with a steep slope will have water flowing quickly towards the river's senile stage while that with a gentle slope has a sluggish flow. Soils play a critical role in regulating flow (Sampson, undated). In addition, the level of fructuring of the underlying material is also important as heavily cracked formations will easily allow fast percolationn of water into aquifers as opposed to the less-fructured formations.

Channel configuration

The shape of the river channel is also important in determining flooding in an area but this requires carrying out a number of numerical modelling exercises in order to understand how changes in land management or channel configuration affects river flow characteristics (Holden, 2014) . This factor is very important because a V – shaped channel will quickly have the stage rise as opposed to a U – shaped channel and worse still with that channel which is saucer –shaped. In Salima and Nkhotakota Districts for instance, the channel of the rivers originating from the upper plateau will normally assume a saucer-shaped formation and these are the areas which are prone to excessive flooding affecting many households because the river channels cannot contain all the flow arising from the upper and middle stages of these rivers.

Basin Area

The size of the basin determines how much flow a particular point or area within that basin can receive that is generated from a storm. For instance, a huge storm occurring within the Namikokwe River Basin with a basin area of $42km^2$ can generate a flood of a sizeable nature when the same storm if occurring within the Linthipe Basin with a catchment area of 8,070km^2 (Malawi Government, 1986) will have an insignificant impact. This is an important observation in flood frequency analysis because it must be recognised that the occurrence of a flood within any given river basin depends on how much that basin is able to accumulate the flow from its tributaries if a single high-intensity storm completely engulfed it.

If the river basins of the region under study show homogeneity, it can be concluded that any single storm generated from common rain-forming mechanisms can occur anywhere within that region and the amount of flooding will depend on the size of the storm and the basin's geophysical characteristics. Therefore if the smallest flood magnitude can be assigned to the smallest river basin and the largest flood to the largest river basin, in that order, it should be possible to analyse the "common" characteristic of the region and the behaviour of floods and flooding over time.

Basin shape

A long thin and deep valley will be able to contain flow within the confines of the river channel while a circular flat basin may disperse the flow. Here again and depending on the basin slope, the rate of flow of the water will be different between basins of different shapes.

Basin location

In large countries the location of the basin is important in determining floods and flooding because of the differences in rain-forming mechanisms, altitude or longitude (Srinivas, 2012). For instance, those areas that are subjected to cyclones such as Seychelles, Mauritius, Madagascar or Mozambique can receive high precipitation leading to unprecedented floods and flooding within those countries. However, in regions where rain-forming mechanisms consist of orography and convection such as in Malawi, the degree of flooding arising from any storm generated in this form may not necessarily be equal to that which is caused by a cyclone. The Central Region of Malawi will therefore only be subjected to orographic and conventional rainfall that causes floods even though migratory cyclonic influences could be experienced.

2.4 Empirical Flood Formulae Developed for Malawi

Three regional flood frequency formulae have been proposed for Malawi by Pike (1971), Drayton (1980) and Krishnamurthy (1987) which are being used by engineers for the design of hydraulic structures and apply to the whole country, including the Central Region.

2.4.1 Pike's Formula

Pike used discharge data to develop a regional flood frequency formula for Malawi which took the form (Pike, 1971):

$$\mathbf{Q = CA^n}$$

Where Q is the flood flow in ft^3/s;

C is a regional coefficient; and

n is equal to 0.5

Due to the heterogeneity of geographical regions in Malawi, Pike (1971) came up with three distinct regions: mountainous, average and flat. He assigned each region with a regional coefficient as presented in Table 4 shown below:

Table 9: Regional coefficients used in Pike's flood frequency formula

REGION		RETURN PERIOD (YEARS)		
Type No.	**Nature of region**	**25**	**50**	**100**
1	Mountainous	2,600	3,000	3,500
2	Average	960	1,200	1,500
3	Flat	500	600	700

Type 1 region in Pike's method would therefore be those areas such as the Mulanje Mountain, the Shire Highlands, Viphya and Nyika which are mountainous and rugged. The Type 2 regions would cover the low-altitude areas of southern region except the Lower Shire Valley, the plateau areas of the Central Region and the northern region with the exception of the Viphya and Nyika plateaux. The third region, Type 3 consists of the lakeshore and the Shire Valley areas which are of low altitude.

2.4.2 Drayton's Formula

Following Pike, four hydrologists Drayton, Kidd, Mandeville and Miller (1980) developed their own flood frequency formula for estimating the T-year flood in Malawi which took the form:

$$\mathbf{Q_{BAR} = 2.89\ A^{0.55}\ .\ STMFRQ^{\ 0.36}}$$

Where	Q_{BAR}	is the mean annual flood in m^3/s);
	A	is the catchment area of the basin in km^2; and
	STMFRQ	is the stream frequency of the basin defined as number of junctions of the river or stream divided by the area.

According to these authors, the results of flood magnitude calculated using this formula proved to be useful only up to a return period of 50 years (Drayton, et. al., 1980). They acknowledged the fact that there is relatively high variability of floods in Malawi which had an average coefficient of variation of 67 per cent; and because they had used data of only 20 years of record, the estimation of the mean annual flood produced a standard error estimate of 15 per cent. Estimation of flood frequency at a regular gauging station was calculated by multiplying the mean annual flood Q_{BAR} with Q_T/Q_{BAR} obtained from the data of the station.

2.4.3 Krishnamurthy's Formula

Another flood frequency formula was developed by Krishnamurthy in 1987 as shown below:

$$\mathbf{Q_T = f\ .\ Q_{BAR}}$$

Where	Q_T	is a flood of magnitude Q occurring once *on average* in T years in m^3/s;
	f	is a flood growth factor; and
	Q_{BAR}	is the mean annual flood for the basin in m^3/s.

Krishnamurthy proposed that the mean annual flood Q_{BAR} for any site within the basin gauged or not, was equal to $3.34A^{0.51}$, where A is the basin's area in km^2. In order to estimate the maximum flood of a given return period, he provided the following "growth factors" which were to be used for a given return period. These growth factors are presented in Table 10.

Table 10: Krishnamurthy's Growth Factors

Return Period (Years)	Growth Factor (*f*)
2	0.9
10	1.94
20	2.35
50	2.88
100	3.27

Pike's formula of 1971 and that developed by Krishnamurthy in 1987 have been used in the design of hydraulic structures over the years by engineers and consultants in Malawi. It becomes necessary to review the results of the various formulae that have so far been in use in the country and investigate similarities or dissimilarities of the results.

2.4.4 Comparison of results of the three formulae

Using the Gumbel distribution, Pike's and Krishnamurthy's formula, the three methods were tested on Namikokwe River with a basin area of 129km^2 above the gauging station. Six return periods consisting of 5, 10, 20, 25, 50 and 100 years were used (Table 11).

Table 11: Discharge magnitudes of the Namikokwe using existing methods and data

NAMIKOKWE 3.E.2 (129 km^2)						
Proposer	**Return Period (Years)**					
	5	**10**	**20**	**25**	**50**	**100**
Gumbel	52.5	68	82.9	87.6	102	117
Pike (1971)	-	-	-	836	965	1126
Krishnamurthy (1987)	-	39.8	93.6	-	115	130
Data	50.9	70	89.2	95.4	114	134

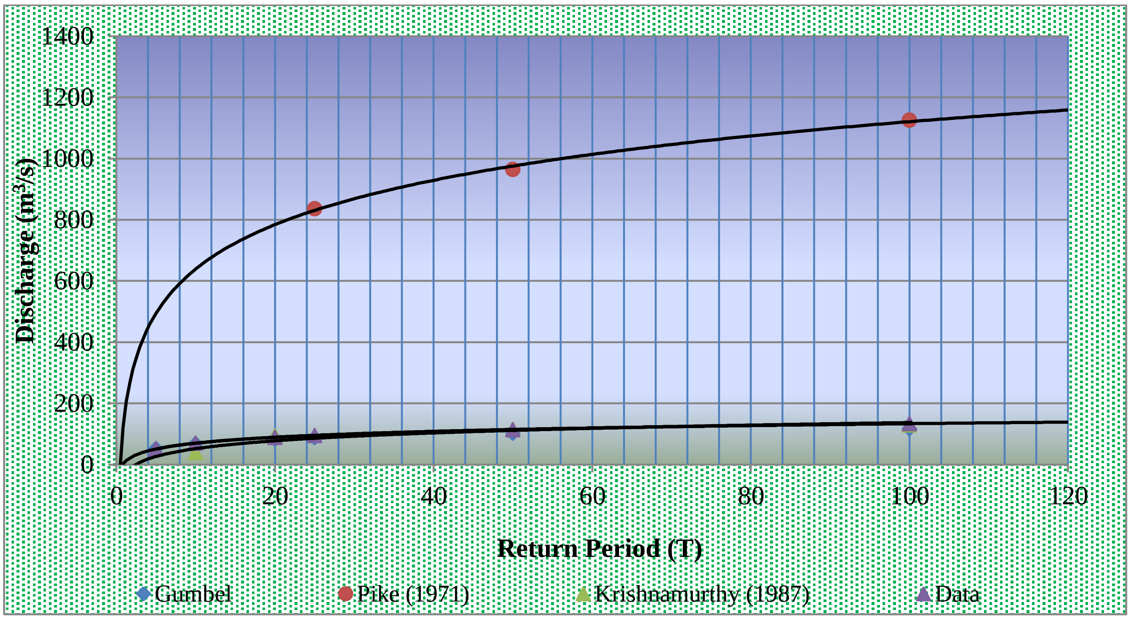

Figure 20: Graphical presentation of the flood flows using existing methods

The results obtained from the various methods were plotted as shown in Figure 20 for visual inspection. As noted, the values obtained from Pike's method are much higher than those obtained using Gumbel distribution, data and Krishnamurthy's formula. Under such a scenario it becomes exceedingly difficult for the design engineer to choose which method to use in his or her work.

In the case of Lilongwe River at Lilongwe Old Town Bridge, there is closeness between the flood estimations obtained using Gumbel distribution, Krishnamurthy's method and data even though there still are some differences (see Table 12 and Figure 21). Exceedingly high values are observed for Pike's method making judgement quite difficult on which method to use.

Table 12: Discharge magnitudes of the Lilongwe using existing methods and data

LILONGWE 4.D.4 (1,870 km^2)						
Proposer	**Return Period (Years)**					
	5	**10**	**20**	**25**	**50**	**100**
Gumbel	192	253	311	330	387	443
Pike (1971)	-	-	-	612	735	857
Krishnamurthy (1987)	-	302	366	-	448	509
Data	186	261	335	359	434	509

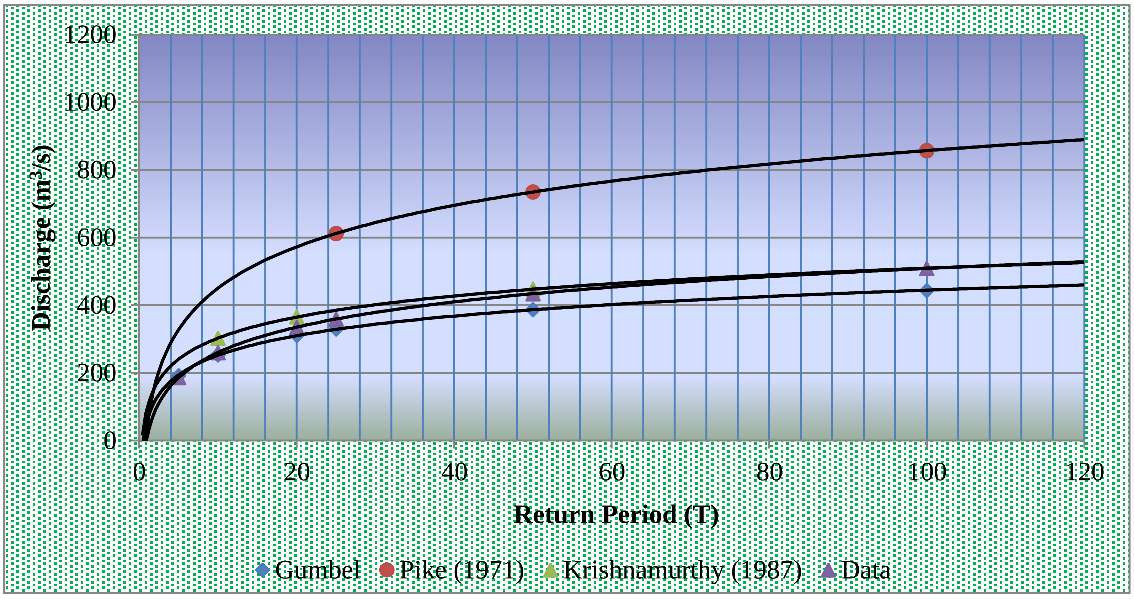

Figure 21: Graphical presentation of the flood flows using the existing methods

Similarly, the three methods were also used for the Bua River on the Lakeshore Road which has a basin area of 10, 600km^2 and is the largest basin area in the Central Region. The results obtained in Table 13 are presented in Figure 22.

Table 13: Discharge magnitudes of the Bua using existing methods and data

BUA 5.C.1 (10,600 km^2)						
Proposer	**Return Period (Years)**					
	5	**10**	**20**	**25**	**50**	**100**
Gumbel	832	1058	1275	1343	1555	1766
Pike (1971)	-	-	-	1458	1749	2041
Krishnamurthy (1987)	-	732	886	-	1086	1234
Data	812	1094	1375	1466	1748	2029

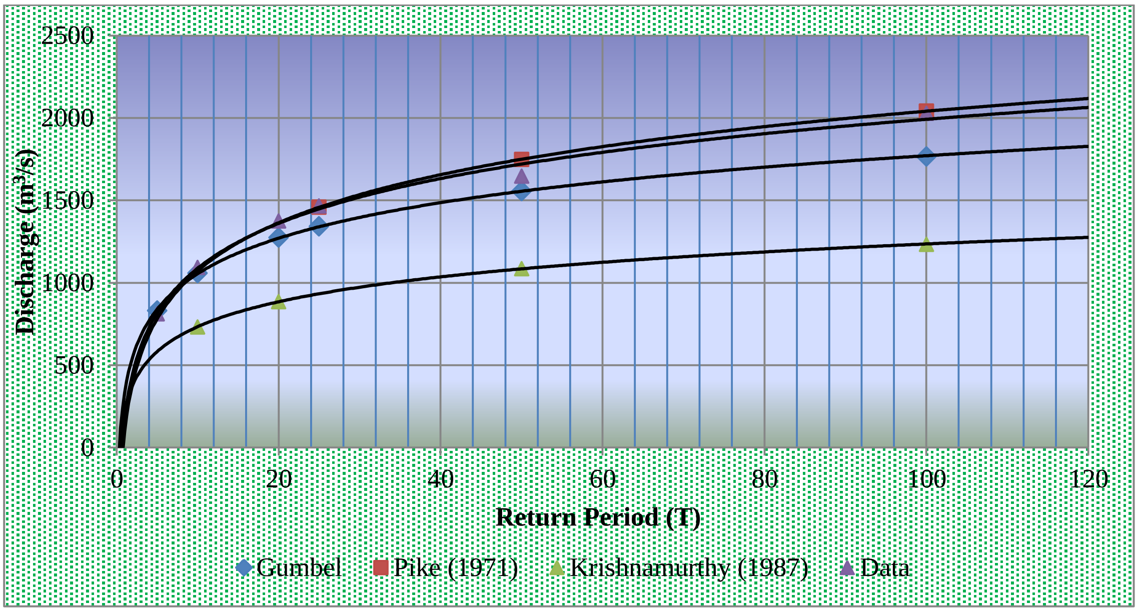

Figure 22: Graphical presentation of the flood flows using the existing methods

In this case, there are again wide variations in the results with Pike's method giving the highest results and Krishnamurthy's method yielding the least. For instance the maximum flow at a return period of 100 years is over 2,000m^3/s using Pike's method while Krishnamurthy's method gives a maximum flows of only about 1,230m^3/s.

Another basin was subjected to the same test that of the Dwangwa with a basin area of 2,980 km^2 located in Kasungu District (See Table 14 and Figure 23). The differences are clearly shown in Figure 23 which gives a strong dilemma on which method can be used.

Table 14: Discharge magnitudes of the Dwangwa using existing methods and data

DWANGWA 6.C.1 (2,980 km^2)						
Proposer	**Return Period (Years)**					
	5	**10**	**20**	**25**	**50**	**100**
Gumbel	142	177	211	222	255	287
Pike (1971)	-	-	-	773	927	1082
Krishnamurthy (1987)	-	383	464	-	569	646
Data	137	179	221	235	277	319

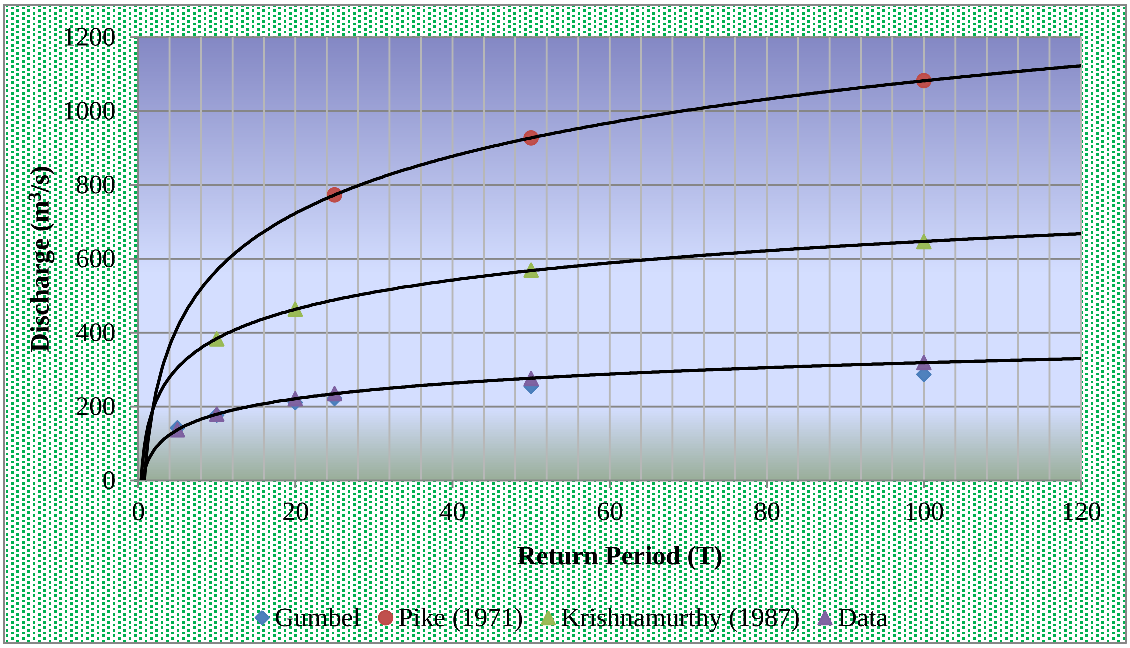

Figure 23: Graphical presentation of the flood flows using the existing methods

In wanting to explore more on the validity of these methods, another river basin on the Lakeshore Plain was chosen – the Lingadzi at Songwe Village whose results appear in Table 15. This river basin has a basin area of 450 km^2 above the gauging station.

Table 15: Discharge magnitudes of the Lingadzi using existing methods and data

LINGADZI 15.A.8 (450 km^2)						
Proposer	**Return Period (Years)**					
	5	**10**	**20**	**25**	**50**	**100**
Gumbel	489	661	826	878	1040	1200
Pike (1971)	-	-	-	577	721	901
Krishnamurthy (1987)	-	146	177	-	217	246
Data	475	690	906	975	1192	1406

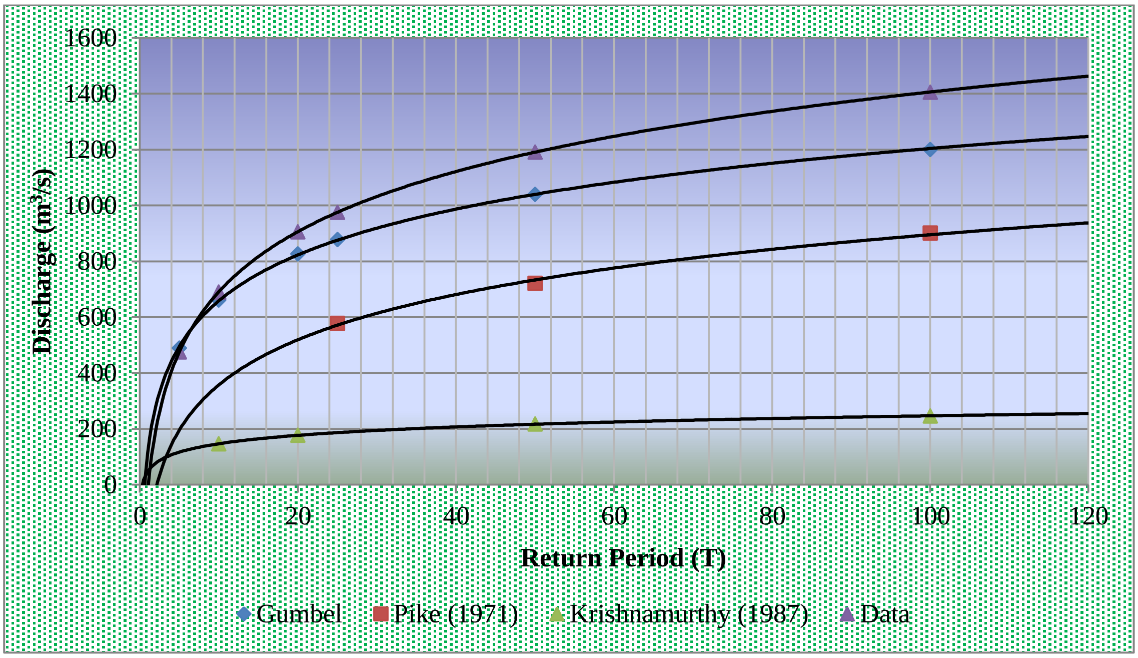

Figure 24: Graphical presentation of the flood flows using existing methods

As will be seen in Figure 24, there are wide variations in the results obtained with the station's data giving high results and Krishnamurthy's method providing the least flows at various return periods. Results obtained using the Gumbel distribution and Pike's method lie between the two extremes but are also significantly wide apart.

2.4.5 Relevance of Historical Empirical Eormulae

From the preceding discussion, it is clear that the methods currently in use pose challenges in deciding their applicability in the design of hydraulic structures. In the case of the method proposed by Drayton et. al. (1980), the stream frequency can be diffuclt to determine depending on the size of topographic used, and this would influence the result of the analysis.

The method proposed by Pike may be regarded as generally acceptable but it limits the engineer in deciding which are the boundaries between mountaneous areas and plateau areas or between plateau areas and flat zones since this is subjective. This is especially true if one were to decide whether the escarpment zone is mountaneous or average or in the case of the Central Region, whether the Dedza and Dowa areas fall within the "mountaneous" or "average" regions for flood calculations.

Krishnamurthy's method of 1987 may still be used but it is limited to calculating flows with return periods of up to 100 years which are dependent on the given "growth factors". As a result of this challenge it then becomes imparative to examine the available flood data for the rivers of the Central Region and propose another flood frequency model for use in hydraulic engineering works and for town and country planning. The challenge faced in deciding which flood frequency method to use has been experienced elsewhere (Thomas Jr. et al, 2015) and has necessitated a review on the applicability of such methods as done in this study.

Thomas Jr. et al (2015) examined the applicability of available flood frequency methods for ungauged catchments in Lake County, California and the Saint Francis County, Arkansas and noted differences in computed discharges for the T-year flood in river basins with the same catchment area as has been observed in Section 2.4.4 of this work. This is absolutely necessary to come up with a more accuratee flood frequency model for the Central Region.

Due to the seemingly frequent occurrence of floods in all the river basins of the Central Region, it is necessary that people begin to learn to live with them. This requires that knowledge on frequency and magnitudes of floods be made available in order to avail planners and engineers the capability to effectively deal with the impacts of floods on people and the environment. The causes of floods and reasons that exacerbate their magnitudes must be well understood and mitigation measures should be put in place. One of the things to do is to promote sustainable land management (SLM), awareness creation on how floods may be triggered by poor land use, the need for capacity building and better land use planning.

2.5 Conclusions

Flood models are not new as they have been developed in different parts of the world to assist in the design of various water-related engineering works. These models have also been developed in Malawi based on various parameters such as the mean annual flood or the stream frequency (defined as the number of river/stream confluences per square kilometre in a river basin). Some of the so called “regional” models developed for Malawi have been subjected to testing for the T-year flood for a few of the river basins of the Central Region and it has been observed that different results are obtained putting the design engineer in a dilemma.

Surface runoff is determined partly by factors that have been highlighted above, and these differ from one area to another, one region to another and may even differ from one country to another. For this reason, a flood frequency model developed for one area cannot necessarily be relevant for another area, and this is why it became necessary in this study to test the various flood frequency models developed in Malawi as to how well they apply to river basins in the Central Region.

From the three flood frequency models (Pike, 1971; Drayton et al, 1980; Krishnamurthy 1987) it has been shown that the design engineer or country planner could face challenges in deciding which model to use as they all provide different results, at times will huge margins. The development of a more accurate regional flood frequency model became an absolute necessity, hence the current study considered the homogeneity of the region ass one of the key parameters for the development of the model.

CHAPTER 3
METHODOLOGY

3. Introduction

The development of a flood frequency model for the Central Region of Malawi was based on the analysis of historical hydrometric data. These data comprised annual instantaneous absolute maximum flows obtained from regular gauging stations in the Central Region. In carrying the analysis, data were examined for their completeness and quality to qualify for use in the ensuing analysis. This was followed by plotting flood magnitude against their reduced variates from which the T-year flood estimates were made.

Prior to the analysis, an inventory of flood events and their associated impacts was produced for selected districts in the region with a view to illustrating the importance of developing the desired "regional" flood frequency model that could be used in the design of hydraulic structures and for producing flood zoning maps.

Stakeholder interviews with local communities in Lifidzi, Lingadzi, Mtiti, Bua, Rusa and Dwangwa River Basins (Salima, Dowa and Kasungu Districts) were conducted in order to gain people's experiences with floods, and how flood hazards affected their social and economic wellbeing and the environment in general. It must be pointed out at the outset that that component of the research work was not part of the core activity of the study but it was felt necessary to gain people's understanding about how flood events disrupted their normal lives. The interviews also did shed some light on what the government should do in order to mitigate flood disasters in the Central Region. One such mitigation measure identified through interviews was the need to delineate flood-prone areas (most likely through the application of an accurate "regional" flood frequency model, the subject of this study)

3.1 Setting the foundation

In compliance with conditions laid down by the University (UNISA, 2013), an Ethics Application Form was submitted to the College of Agriculture and Environmental Sciences in October 2013 for approval to undertake research in the selected river basins. Page 1 of the submitted application form appears as Annex I in this report. In addition and as required by the University, authorization and a Letter of Introduction were obtained from the Ministry Agriculture, Irrigation and Water Development in Malawi granting permission to visit the selected river basins and conduct interviews with local communities on the occurrence, impacts and frequency of floods and flooding in their respective areas and hear their views as to what the government should do in order to mitigate adverse impacts of flood hazards. The Letter of Introduction is presented as Annex II in this report. This requirement was in fulfilment of Section 3.1 of the Guidelines for Conducting Research involving UNISA staff, students or data (UNISA, 2012).

3.2 Approach towards field investigations

Prior to collecting data from the field, it was necessary to choose one research method to adopt. The method that was chosen was mainly influenced by a number of factors, including the following:

(a) The size of the study area;

(b) Distances from base to the river basins;

(c) Need to get first-hand information about adverse impacts of floods from flood victims and their perceptions on what needs to be done; and in so doing, avoid receiving information through third parties on the same which could be misleading;

(d) Need to obtain information from the respondents in confidence, such as data on their economic status in the form of annual household incomes, their assets and whether they think their livelihoods are improving or not. Such information, it was thought, could not be divulged to third parties; and

(e) Investigating the main causes of land degradation within the basins of the Central Region which again, other people may not be aware of if this work were to be delegated.

More than one research method could have been used for data collection, including the following (University of Bradford, undated):

(i) ***Exploratory research*** which is carried out with a view to investigating any

patterns, hypotheses or ideas that a researcher seeks to test and form a basis for future work;

(ii) ***Descriptive research*** that identifies elements of characteristics of the work being considered;

(iii) ***Analytical research*** which answers the questions of *why* or *how* something is happening and often has a description of the causes of the phenomena; and

(iv) ***Predictive research*** that provides ideas of what is likely to occur into the future based on objective assessment of what is happening at the present by considering the causes and effects of the phenomena.

In this regard, the third category of research was adopted to seek answers on why floods were becoming prevalent in river basins in Malawi which never before experienced such frequent events, and what the causes *could be* that make floods occur with such increased intensity and frequency.

3.3 Nature of the Field Surveys

In order to find answers to *why* and *how* floods are becoming frequent in the Central Region, it was also necessary to adopt a suitable approach in obtaining such information. Historical data on river flows recorded in ledgers assisted in providing the general trend of flood flows within the river basins over the decades based on the hydrographs generated. However, the frequency of occurrence of these flows remained unexplained until a flood frequency analysis was performed.

Field surveys mainly involved interviews with local communities in six river basins. A questionnaire was prepared which indicated the administrative district in which the interviews were to be conducted, the name of the respondent, his/her village, questions to be asked and empty spaces in which the answers were to be recorded. A sample of the questionnaire that was used appears as Annex III in this report, and corresponding consolidated answers from the respondents are presented in Annex IV.

3.4 Period of the investigations

Field visits were undertaken to selected river basins of Livulezi, Namikokwe, Nadzipulu, Lipimbi, Nkula and Lingadzi on 6th and 7th September, 2014 and was followed by another visit to the Plateau river basins on the 13th and 14th of the same month. During the second visit communities living in the river basins of Mtiti, Bua, Rusa and Dwangwa were interviewed.

3.5 Selection of river basins and respondents

The choice of which river basins to visit was made based on the differences that occur between communities that live along the Lakeshore who are dependent on cotton and rice as their main household cash earner and those that reside in the plateau areas of Dedza, Lilongwe, Mchinji, Dowa, Ntchisi and Kasungu who are principally dependent on tobacco as a cash crop. The intention was to investigate people’s livelihoods, social and economic wellbeing and assess what influence these social and economic dimensions have on land use. It was interesting to hear directly from the people living in the two physiographic regions whether land use practices contribute to flooding or not.

To avoid bias, the choice of respondents was random. The respondents included mat and basket weavers (who do this to earn extra cash over and above what they get upon selling their crops), old men and women principally dependent on agriculture, Grade 8 students (who had finished writing their examinations and were waiting to enter secondary school. These are not juveniles but have an understanding of what affects them and could affect their future wellbeing in the country), middle-aged men who were both business persons and farmers and a retiree from the civil service. In this regard therefore, the sample of interviewees took into account gender by including men, women and the youth and also contained two distinct groups comprising those that have and have not been to school.

3.6 Raw field information and analysis

Data was analysed on the basis of social, economic and environmental aspects, see Annex IV. It is clear from the responses given that people think that land use is partly to blame for the occurrence of floods in the Central Region. For instance the majority of the people indicated that tobacco was the main culprit for deforestation and land degradation as poles are needed almost on an annual basis for the construction of tobacco sheds especially for burley and for processing flue cured tobacco. Annex III shows a sample of the answer sheet for Mrs. Mary Jangiya and Andrew of Zelembe Village Traditional Authority Kaomba in Kasungu District, in the Dwangwa River

Basin.

3.7 Methodology for addressing Specific Objective 1

The documentation of flood events and their impacts within the region was necessary and critical in that it forms the basis for future studies; and secondly, it illustrates the pressures and impacts on the environment and highlights the responses that the government and other non-governmental agencies have undertaken in the past to mitigate the impacts of flood disasters. This is another specific objective considered very important to the study as the most frequently-occurring hazards in Malawi are floods and that they will continue to regularly affect the country (Misomali, undated). According to USAID, recent climate models seem to suggest that there will be an increase in the frequency of not only droughts but also floods in the country (USAID, 2012).

Once a flood incident takes place, the Department of Disaster Management Affairs and other national and international aid agencies usually prepare and publish bulletins on the levels of infrastructure that has been destroyed, people affected, crops and animals lost and their total engagement in material and financial support. Losses caused by floods can be huge and involve substantial financial resources which government must mobilise.

Albeit being only a short period from 2000 to 2003, this sample of floods and flooding within the region clearly shows the levels of devastation that are associated with floods and such a chronology of events must be continuously documented. More importantly, while this information only show where the floods occurred and their levels of destruction, the development of a flood frequency model would show where a T-year flood is likely to occur and assist the highway engineer or country planner to make informed decisions and prevent such losses as those that took place during the period 2000 – 2003.

3.8 Methodology for addressing Specific Objective 2

As a result of the flood disasters that Malawi has been experiencing over the years, three flood frequency models have been proposed by hydrologists and engineers for use in flood frequencies and their associated magnitudes (Pike, 1971; Drayton, 1980; Krishnamurthy, 1987). These methods have been discussed in detail in this study. The main focus of carrying out this Specific Objective was to examine the applicability of these formulae as design tools in both gauged and ungauged catchments. In light of the above, a few gauging stations were selected from geomorphologically and topographically different areas and their data were applied to existing models to see if the results would be identical. This process involveed the following flood frequency models:

For Pike's method (1971):

a) Choose a basin with a known and unknown basin area (km^2);
b) Use the given formula to get the 25, 50 and 100-years floods (m^3/s); and
c) Plot the results.

For Krishnamurthy's method (1987):

a) Choose a basin with a known and unknown basin area (km^2);
b) Calculate the mean annual flood from the data and use that given by Krishnamurthy for the ungauged catchment (m^3/s);
c) Employ the formula to obtain the design floods at different return periods using the "growth factors" given by Krishnamurthy (m^3/s); and
d) Plot the results.

Probability plots (Wilson, 1974):

a) If the probability of occurrence $\boldsymbol{p}$ of an event is 1/n+1 where n is the number of events, then the probability of non-occurrence $\boldsymbol{q}$ is 1-1/p. Therefore assemble the annual maximum flows for the selected station of the region to be used in the study and obtain the probabilities of occurrence and non-occurrence;
b) Calculation of reduced variates for each flood magnitude for each station to obtain the plotting positions;
c) Find the corresponding return periods for the reduced variates and make plots for the T-year floods; and
d) Plot all the results obtained from the different methods and see how they compare.

3.9 Methodology for addressing Specific Objective 3

Several flood frequency models were assessed for their accuracy in determining extreme flows for each river basin at various return periods. Runoff from any catchment area is dependent on rainfall characteristics, soil type, slope, vegetation cover and other parameters. This is why, after the extensive application of empirical formula in the recent past, there has been many other formulae developed with a view to improving the accuracy of estimating the magnitude of floods. The early empirical formula such as the Rational Method becomes only useful to small catchments as it is dependent on point design rainfall intensity (Pegram et al, 2004).

The intention in this study was to use data comprising maximum discharge values and generate best-fit relationships between flows and the mean annual flow ($\bar{Q}$) at each station and the basin area (A). These relationships formed the basis for investigating correlations that exist between the T-year flood flows and cluster a "family of basins" which show similarities between *any* of these relationships. Having come up with a clear relationship between any of the above variables and maximum flood flows, a regional flood frequency model was developed that has potential use in the design of hydraulic structures.

3.10 Conclusion

Various methods for addressing the three specific objectives have been discussed and they include field investigations. The whole process of acquiring data from rural communities on what they know about drivers of floods and flooding, pressures on the environment, the state of the present ecosystems within the region, impacts of anthropogenic activities and the resultant responses by government during floods and flooding was carried out in compliance with approved ethical procedures recommended by UNISA (UNISA, 2012).

The choice of rivers was based on water resources areas located in the Central Region, and the inclusion of a river or river basin was determined by carrying using randomisation in order to remove bias. A chronology of floods and their impacts on local communities and the environment has been compiled. What becomes critical from these flood events is to determine their magnitudes and frequency of occurrence so that future impacts of such events could be mitigated or minimised. It has generally been noted that the frequency of flooding in Malawi is increasing (Misomali undated, and USAID, 2012); and this is the more reason why the development of a regional flood frequency for the Central Region was an absolute necessity.

CHAPTER 4
HYDROLOGICAL DATA ANALYSIS, FIELD INVESTIGATIONS AND DEVELOPMENT OF THE MODEL

4. Introduction

This chapter begins with a discussion of flood events in the Central Region and a sample of some of the flood occurrences that have occurred in the districts of the region and their impacts are documented. This is meant to emphasize the need for systematic documentation of floods by the Ministry responsible for water affairs in Malawi as well as that Ministry which is responsible for disasters so that the information can assist in river basin planning and development. Positive and negative impacts of floods are discussed in this chapter which also explains what responses are taken by both government and non-governmental organisations when floods occur and especially when they have caused havoc and disaster.

This is also the chapter where the new flood frequency model is developed. However, before this development, an examination of the annual instantaneous maximum flood data is made so that it is adequate in terms of quality and quantity for the development of the model. River basins are tested for their homogeneity under this chapter so that the new model can indeed be regarded to be "regional". A case is made of the authenticity of the new model for use by planners and design engineers in the Central Region.

Finally, the chapter discusses people's livelihoods in the region and goes further to present some experiences of the communities during floods and what they think are the causes of floods and flooding and what should be done to lessen the suffering of the people and reduce damage to infrastructure.

4.1 Documentation of flood occurrences in the Central Region

All the administrative districts falling within the confines of the study area such as Dedza, Lilongwe, Dowa, Mchinji, Kasungu, Salima and Nkhotakota have experienced floods of varying magnitudes. As the waters cascade the Escarpment Zone from the plateau areas, there is increased runoff which eventually ends up causing flooding in the lower reaches of the Lakeshore Plain. Over the plateau there have also been instances of floods and flooding especially within the Lilongwe, Bua and Dwangwa River Basins which have been responsible for the destruction of infrastructure and loss of property.

Poor land management through deforestation and inadequate land use practices has led to frequent occurrence of floods in Central Region even in those areas where such incidences never occurred during the past decades. Huge volumes of water cascading the mountain slopes of the Dedza Massif and lower hills like elsewhere in the region have been responsible for scouring river banks (See Figure 25) sometimes washing away bridges and the road infrastructure. During a field tour of WRA 3 (South-Western Lakeshore), it was observed that many of the rivers such as Livulezi, Namikokwe and Nadzipulu are often subjected to scouring of the river banks during floods and this is particularly so because of the nature of the soils which consist of alluvials most dominant in the lakeshore zone.

Figure 25: Livulezi River upstream of the bridge on M5 Road

Source: Elton Laisi (2014)

A major secondary road linking the south, centre and the north passes through the lakeshore across which the rivers flowing from the Escarpment Zone pass. Most of the bridges on this road and the road infrastructure itself are at risk from being washed away by a large flood. As one large flood passes each year, engineers come back to protect the river banks and sometimes the bridges with gabion baskets to prevent the infrastructure from total collapse (refer to Figure 25).

4.1.1 Floods and their impacts on the environment

A flood can be defined in many ways depending on the aspect to which it is related or referred. For instance, in Australia (Government of Australia, 2015) the government introduced a ordinary definition of a flood in 2011 which was so defined because of its implications on insurance policies. However, a flood is a natural phenomenon involving the accumulation of water over land which is normally dry that occurs during or after precipitation. Depending on the magnitude of the event, a flood can cause great destruction and loss of life and property including:

- Generation of mudslides which can completely bury a community;
- Damage to hydraulic structures;
- Destruction of or wiping away crops in agricultural areas;
- Destruction of homes, roads and other structures;
- Erosion of landscapes;
- Escavation of sacred areas; and
- Changes or modification of habitats.

A chronology of flood occurrence in the Central Region has been isolated from available records for the period 2000 – 2003 and this is presented in Table 16 and discussed in Section 4.1.2. These data are representative of the nature of destruction and loss of property within the region which continues to occur up to now signifying the great suffering that people go through and the huge economic losses that government is subjected to.

In 2000 floods destroyed homesteads and swept away crops in Nkhotakota District and more destruction followed in 2001 when villages in Mchinji, Salima, Nkhotakota and Kasungu Districts were affected. Only Nkhotakota Ditrict suffered from floods during 2002 but the year 2003 saw houses damaged, crops washed away and bridges destroyed and washed away in Dedza, Dowa, Lilongwe, Salima, Nkhotakota and Mchinji Districts (Willy and Partners Engineering Services, 2005).

Table 16: Impacts of floods in the Central Region 2000 - 2003

DATE/ PERIOD	EVENT	LOCATION	IMPACT
March, 2000	Flooding within the river basins of Kaombe, Likowa, Lifuliza and Liudzi.	Villages in T.A. Mwadzama and T.A. Malengachanzi areas in Nkhotakota District.	148 households had their houses damaged. 1,764 households lost their crops.
January, 2001	Flooding within the Tete River Basin.	A number of villages in T.A. Kaphuka in Dedza District.	106 households had their gardens and crops washed away.
January, 2001	Floods	Villages in Traditional Authorities of Dambe, Mkanda, Mlonyeni and Zulu and S.T.As Kapondo, Nduwa, Mavwere and Simphasi in Mchinji.	2,000 households (10,000 individuals) were affected.
February, 2001	Floods due to flooding of Lingadzi River, Lipimbi River and Chitala River.	23 villages in TAs Khombedza, Chikombe, Kuluunda, STA Ndindi and STA Msosa in Salima.	9,000 households (45,000 individuals) affected. 6,048.4 hectares of maize, 962.00 hectares of rice and 762.6 hectares of cotton were affected. 3 people lost their lives.
February, 2001	Floods	Zidyana and Nkhunga EPA in Nkhotakota.	15,450 households were affected and lost 559 hectares of maize and 748.7 hectares of cassava.
March, 2001	Flooding of Chinkhuti Stream, Nadzipulu River, Livulezi Stream, Namikokwe River and Mphandamadzi	T.A. Kachindamoto and T.A. Chilikumwendo in Dedza district.	869 households (4,345 individuals) affected, had their gardens washed away, 4 houses collapsed, 2 goats and 2

	River.		cows died.
March, 2001	Floods	A number of villages in T.A. Kaomba and S.T.A Chambe in Kasungu.	1,440 individuals affected and some lost their houses and gardens
January, 2002	Floods due to flooding of Dzongwe, Mauni and Mtamba.	GVH Nkhwidzi and Ngodzi areas in Salima District.	185 households affected and had their crops and livestock washed away.
April, 2002	Floods	Linga, Khunga and Zidyana EPAs in Nkhotakota District.	7,258 families had their crops washed away.
January, 2003	Floods	Mtakataka and Golomoti areas in Dedza District.	578 families had their houses damaged and 8,483 families had their crops (1,316 hectares) washed away.
03 January 2003	Flooding of Totolonga River and Chaliwa River.	A number of villages in T.A.s Nsakambewa, Chiwere and Chakhadza in Dowa District.	190 families had their houses damaged and 2,980 families had their 559 hectares of crops washed away. Mtiti Bridge on the M1 Road to Mzuzu and Nkhathwe bridge was washed away.
03 January 2003	Floods	A number of villages in T.A Chitukula in Lilongwe District.	120 families had their houses damaged and their 34 hectares of crops was washed away.
4 January 2003	Flooding of Lilongwe, Linthipe and Lifidzi rivers.	T.A. Ndindi and Maganga in Salima.	3,000 households had their houses damaged and 24,568 families had their gardens washed away.
February, 2003	Flooding of Bua River.	A number of villages in T.A. Mphonde	97 families had their houses damaged

		in Nkhotakota.	and 1,113 families had their crops (213 hectares) washed away.
February, 2003	Floods	STAs Mduwa and Kaponda in Mchinji.	2,052 families had their houses damaged and 1586 families had their crops washed away.

Source: Willy and Partners Engineering Services, Blantyre (2005)

4.1.2 Negative impacts of floods and flooding

Incidences of flooding even in small catchments have been observed on the upper plateau. In 2003, a huge and sudden flood occurred within the Mtiti River Basin in Dowa District and this flood swept away the bridge on the M1 Road that connects Lilongwe to the northern districts of the country (See Figure 26). Such occurences can be attributed to poor land practices and the absence of vegetal cover in almost the entire region save for those parts that are gazetted as protected areas. Today, primary vegetation in the region can only be found in protected areas or in sacred areas such as graveyards (Dudley, et al, undated).

Figure 26: Mtiti Bridge in Dowa District swept away by a flood in 2003

Source: Nation Newspapers Limited (2003)

4.1.3 Positive impacts of floods and flooding

Although floods are generally regarded as destructive and therefore viewed negatively, there are some advantages with which they can be associated even though the destructive nature of floods outweighs the advantages. Some of the advantages include replenishing low-level reservoirs, bringing in of fertile silt to low-lying agricultural lands, conveying rich nutrients for growth of riverine vegetation and the growth and multiplication of food for aquatic life such as fish and the raising of the water table in dry areas (APFM, 2014).

4.1.4 *Response measures taken during floods*

As a response mechanism, the traditional way of dealing with floods in the country begins with an assessment of the damage caused by floods in areas that are affected. Upon compilationn of the full field report, the government may, depending on the magnitude of the disaster declare such an area, "a disaster area" and will issue out a call (Masina, 2015) for assistance to the affected population. Both it, aid agencies and sometimes the private sector come in to provides assistance to affected communities which may be in the form of (DfID, 2015):

- Tents;
- Mats;
- Blankets;
- Kitchen utensils;
- Maize flour (and some can provide rice);
- Protein foods (such as beans, soya)
- Seed for re-planting;
- Farm implements; and others.

However, continuous assistance to affected communities during floods will never be a sustainable solution other than isolating the root causes of these floods and coming up with mitigation measures that will reduce some of the negative impacts.

4.2 Examination of River Flows

A total of 20 hydrometric stations have been selected for analysis of flow data in this study which have also been used for the development of the regional flood frequency model. These stations are in the five WRAs that include the South-Western Lakeshore (3 stations), Linthipe River Basin (9 stations), Bua River Basin (3 stations), Dwangwa River Basin (2 stations) and the Nkhotakota Lakeshore with 3 stations. For each of the WRAs an examination of the history of the hydrometric stations is made with a presentation of the river flows to assess the degree of continuity of data collection and investigate the proportion of missing data.

A general assessment of the quality of data is also made and the magnitude of the floods over the years in those river basins is narrated. Although some of the stations were opened prior to 1971, all the data in this study were obtained from 1971 which had already been processed by the ministry responsible for water affairs from departmental ledgers which show the water level, the date when the discharge measurement was taken and by whom and the actual flow obtained.

In order to have some confidence on the type of data being used for this study it was found necessary to examine the continuity in the data series and have an idea, though only for a relatively short period, how the floods were occuring in magnitude since 1971 for all the 20 stations used in this study. The type of station, the flows, quality of data and known impacts of floods within that basin are discussed. Some of the data is from stations with automatic water level recorders while the rest of the data is from manual stations where records are taken at 06.00 hours and 18.00 hours every day.

4.2.1 Instentaneous maximum flow data from the five river basins

Before developing the flood frequency model, it is critical to examine data quality used in the study.

South-Western Lakeshore Basin

This region consists of small river basins that cover the eastern and south-eastern slopes of the Dedza Mountain extending eastwards towards the lake. The region is generally covered by forests even though there are pockets of clear landscapes being settlements and cultivated lands. Slopes are particularly steep to very steep over the Escarpment Zone and the basin enters a flat area as it approches the lake dominated by alluvials, calcimorphic and hydromorphic soils and the land is moderately settled and cultivated. To the north, the region shares a common boundary with the Linthipe River Basin. The major rivers in this basin are the Lisangadzi, Kabudira, Bwanje, Livulezi, Namikokwe, Nakaingwa and the Nadzipulu. Of these rivers, those that are within the Central Region and are selected for this study including their river gauging stations (RGS) are:

- Namikokwe at Mua, RGS 3.E.2;
- Livulezi at Khwekhwelere, 3.E.3; and
- Namikokwe at Kampanikiza, 3.E.5.

<u>Namikokwe at Mua 3.E.2</u>

Figure 27 shows the maximum flow hydrograph for the Namikokwe River at Mua from 1971 to 2002. This gauging station was opened on October 20, 1957 (Malawi

Government, 1986d) at Mua Mission and has a basin area of 30.1km^2 which is mainly covered by forest. From the available data collected for this study, records indicate continuous data collection from the station with breakages from 1978 to 1980 and from 1998 to 2000. As will be evident from Figure 27, the annual absolute maximum flows are adequate for the purpose of this work even though the missing data for those other years when the station became unoperational could have added more value.

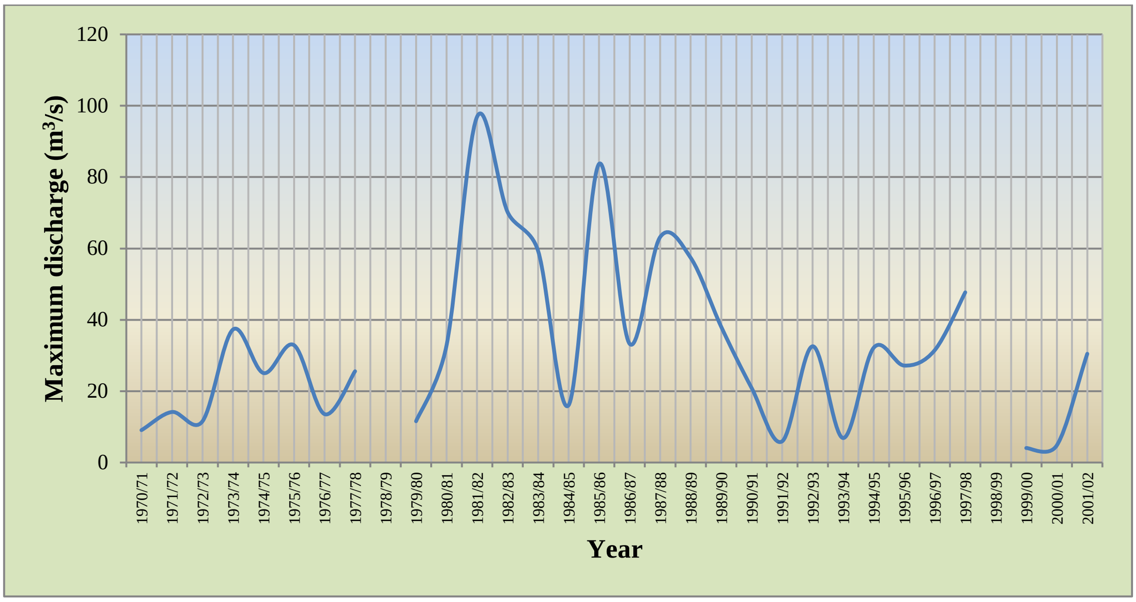

Figure 27: Absolute maximum flows for Namikokwe at Mua (1971-2002)

The annual absolute maximum flows for each othe 20 RGSs were tabulated for their respective number of years and were ranked from the largest to the smallest. To obtain the expected return period T for a particular flood of magnitude Q, the following formula was used:

$$\mathbf{T = (n+1)/m}$$

Where n is the number of years of record; and

m is the rank number for the particular flood of magnitude Q.

The probability that a flood of magnitude Q will be equalled or exceeded in any one year is given by the formula:

$$\mathbf{P = 1/T}$$

Where P is the probability of a flood being equalled or exceeded; and

T is the return period.

The probability values for each and every flood and for each RGS were calculated in order to get the probabilities of non-occurrence of a flood of magnitude Q. Since P is given by 1/T, then the probability of non-occurrence P′ of that flood is:

$$\mathbf{P' = 1 - 1/T}$$

For each of these station, the reduced variates for the given probabilities of non-exceedence were also calculated using the formula:

$$\mathbf{y = -\ln\left\{-\ln\left(1 - 1/T\right)\right\}}$$

Where y is the reduced variate; and

T is the return period.

The values of Q, T, P, P' and y for each of the 20 RGSs are presented in Appendices B to U of this study.

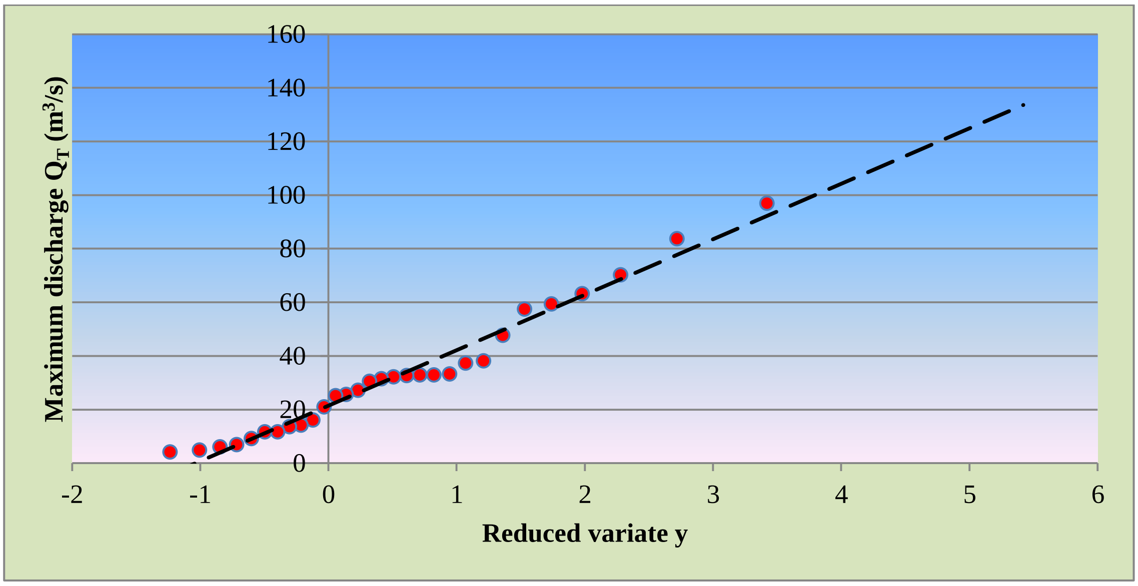

Figure 28: Plot of T-year flood for the Namikokwe with its reduced variate y

A plot of the reduced variate y and Q for the Namikokwe at Mua produced an extremely good fit as will be seen in Figure 28. This plot produced a relationship defined by:

$$Q_T = 20.695y + 21.446$$

and had a correlation coefficient R^2 of 0.97

Despite having no automatic water level recorder, the data shows that both the low levels and high levels were effectively captured by the gauge readers over the years.

<u>Livulezi at Khwekhwelere 3.E.3</u>

This station is located on the upper slopes of the Escarpment Zone and was opened on October 16, 1957. Twice daily stage readings have been taken from this station from which their corresponding flows have been calculated using reguarly updated ratings. The station was once in a densely vegetated area which however is currently settled and moderately cultivated. From the available data, it is observed that there was continuous collection of water levels and flows from this station from 1971 to 1974 but there was a break in records from 1975 to 1979. This break was repeated for the period 1991 to 1997 when activities improved up to 2008. The breakage in data collection and processing is attributed to wash aways of the gauge plates at the site during floods (Malawi Government 1986d).

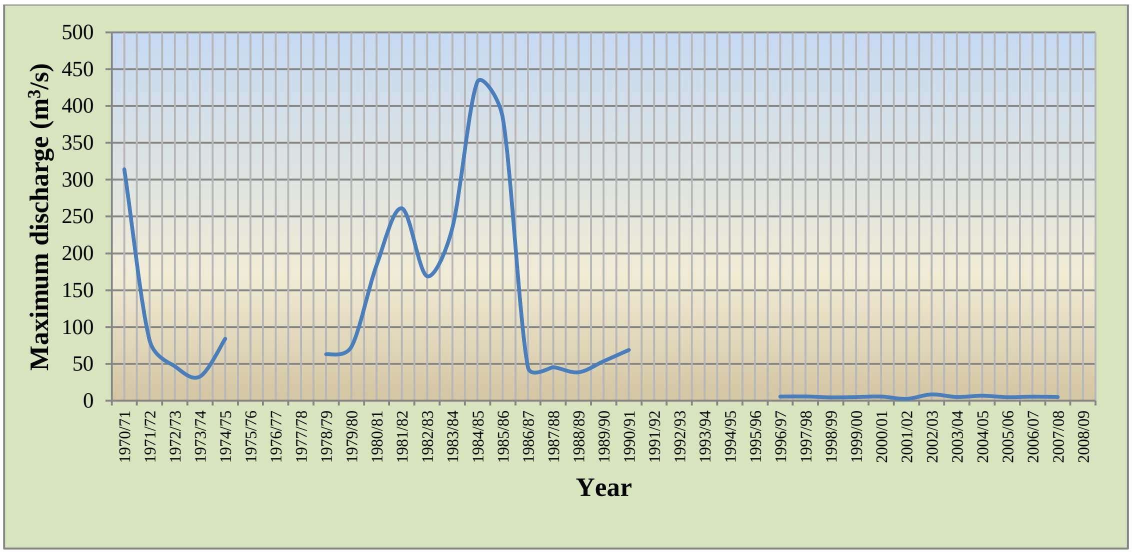

Figure 29: Absolute maximum flows for Livulezi at Khwekhwelere (1971-2008)

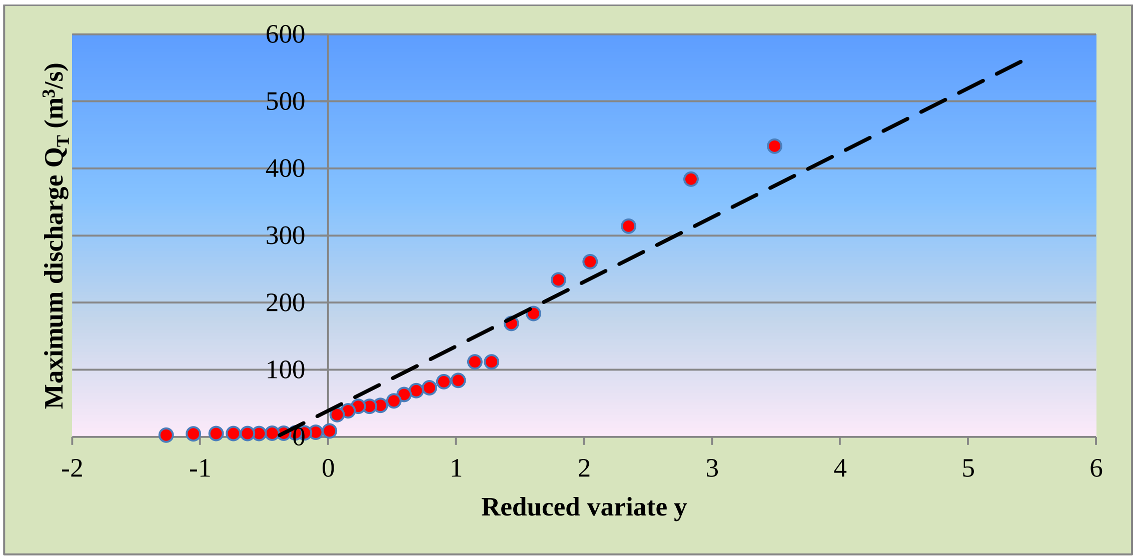

Figure 30: Plot of T-year flood for the Livulezi and its reduced variate y

Figure 29 presents the hydrograph for the annual absolute maximum flows for the Livulezi at Khwekhwelere. Extreme high flows were experienced from 1971 to about 1972 and more significantly high flows occurred from 1980 to 1987. It is not possible to gauge the magnitude of flows from 1991 to 1997 due to non-existence of data but from 1997 to 2008 the river had been sluggish. A plot of the reduced variate y and Q for the Livulezi at Khwekhwelere produced a reasonably satisfactory relationship as will be seen in Figure 30. This plot produced a relationship defined by:

$$Q_T = 96.075y + 38.756$$

and had a correlation coefficient R^2 of 0.89

Being a secondary RGS where no automatic water level recorder has been present it can be expected that readings were compromised by the time the gauge reader went to take readings and the frequency of readings. This could be the reason why there is vivid dispersion of the plots for this station and the relatively low correlation coefficient of 0.89 as compared to other stations in this study.

<u>Namikokwe at Kampanikiza 3.E.5</u>

This station was opened in February 1958 (Malawi Government, 1986d) and is said to have been located in a small gorge in the upper reaches of the river. It has had no automatic water level recorder since it was opened and water level readings are taken twice a day. Because of the steep gradients that characterise the area, few settlements may be seen within the basin. According to the ministry responsible for water affairs, the change in rating between low and medium to high flows is observed at a gauge height of about 0.7m as the channel configuration changes (Malawi Government, 1986d).

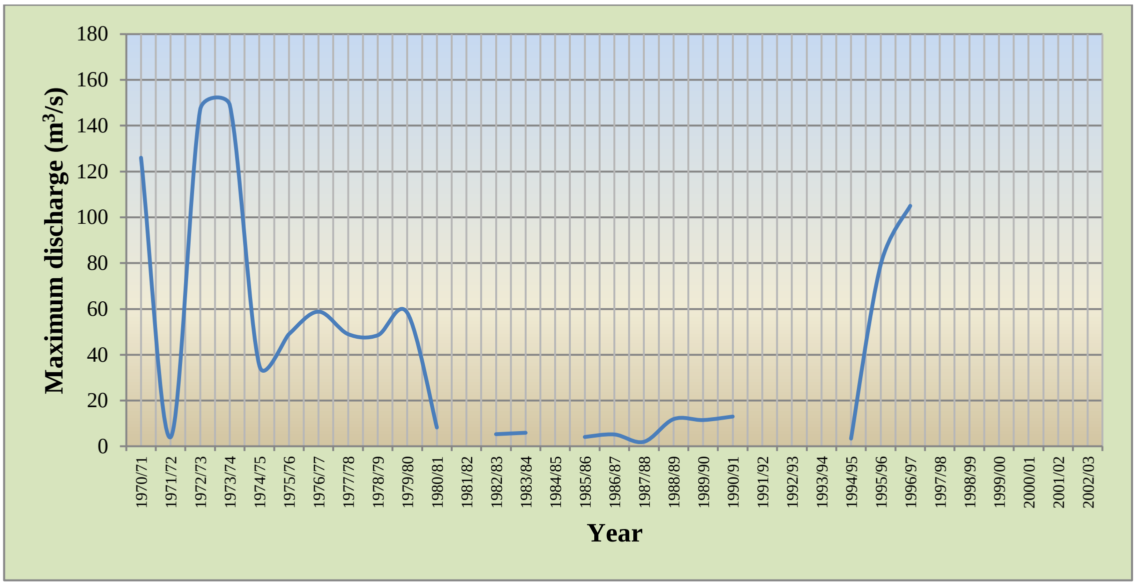

Figure 31: Absolute maximum flows for Namikokwe at Kampanikiza (1971-1997)

The flow hydrograph for this station shows consistency in data collection from 1971 to 1981 when there was a two-year break of poor data which therefore was not considered for use. Another break took place between 1984 and 1986 and between 1991 and 1995. Thereafter there are no high flow records for this station starting from 1997 (see Figure 31). A plot of the reduced variate y and Q for the Namikokwe at Kampanikiza produced a reasonably good fit as will be seen in Figure 32. This plot produced a relationship defined by:

$$Q_T = 39.526y + 20.245$$

and had a correlation coefficient R^2 of 0.91

Within the South-Western Lakeshore Basin, a number of floods have occurred and have been responsible for destruction of property. In March 2001, rivers such as Chinkhuti, Nadzipulu, Livulezi, Namikokwe and Mphandamadzi caused floods in a number of villages in the area of Traditional Authorities Kachindamoto and Chilikumwendo in Dedza District where 4,345 individuals were affected losing their gardens in the process (Willy and Partners Engineering Services, 2005).

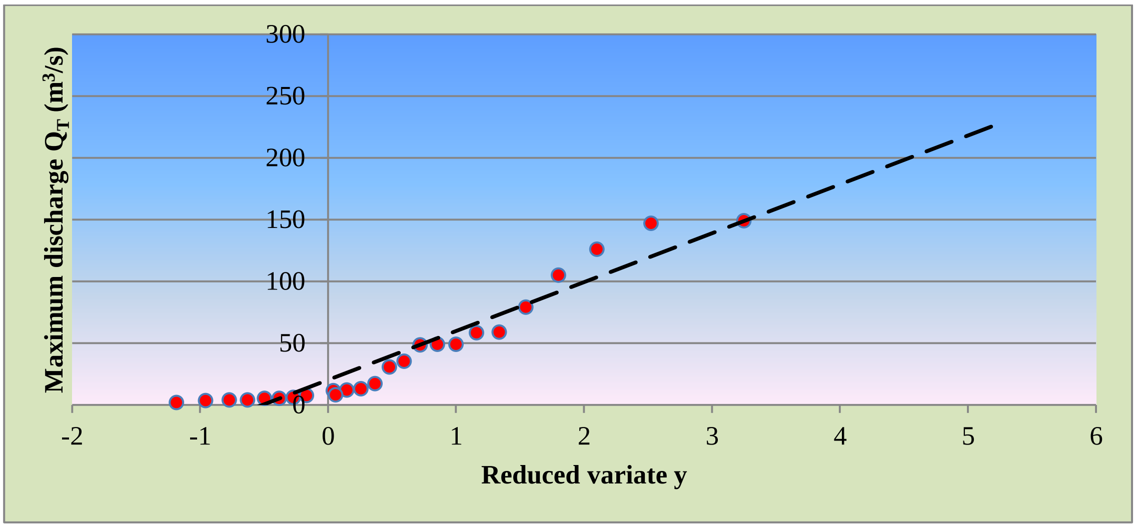

Figure 32: Plot of T-year flood for the Namikokwe with its reduced variate y

During this time 4 houses were destroyed, 2 goats and 2 heads of cattle died. In January 2003, the Mtakataka and Golomoti areas were under floods and 578 families lost their houses and 1,316 hactares of crops were completely washed away by these floods (Willy and Partners Engineering Services, 2005). In addition, the Livulezi Bridge is also known to have been washed away by earlier floods necessitating replacement by a Baily bridge which was later replaced by a concrete one.

Linthipe River Basin

The Linthipe River Basin is the largest of the river basins over the plateau (Malawi Government, 1986b). To its south is the South-Western Lakeshore Basin while to the west it is demarcated by the international boundary between Malawi and Mozambique. The Bua River Basin lies to its north and the basin becomes narrow as it reaches the Escarpment Zone with a breadth of not more tha 5km upon its entry into the Lakeshore Plain. Lilongwe River Basin lies in this super-basin. Within this basin, the major rivers are the Lifisi, Tete, Lifidzi, Diamphwe and Lilongwe with its numerous tributaries which include the Katete, Likuni, Nathenje, Nanjiri, Lingadzi and the Lumbadzi. From this dense network of rivers, those that were selected for this study and their existing river gauging stations are:

- Linthipe at Salima Rail Bridge, 4.B.1;
- Linthipe at Linthipe 4.B.3;
- Linthipe at Malapa, 4.B.9;
- Lilongwe at Mkwenembela, 4.C.2;
- Lilongwe at Old Town, 4.D.4;

- Likuni at Malingunde, 4.D.6;
- Lingadzi at M1 Road Bridge, 4.E.1;
- Lingadzi at S11 Road Bridge, 4.E.2; and
- Lumbadzi at Simakuni, 4.F.6.

This large selection of stations from this one superbasin within the Central Region is due to the high density of RGSs that are available compared to the Bua and Dwangwa where only a few are available. In addition, its large size also justifies the selection of more stations compared say, to WRA 3 which is smaller. Absolute maximum flows for each of the stations listed above were isolated from available records and for each of these an examination of the individual hydrographs is made.

Linthipe at Salima Rail Bridge, 4.B.1

The station was opened on February 1, 1953 (Malawi Government, 1986b) and is a primary station. It is located at the rail bridge between Salima and Chipoka in a very flat area within the lakeshore plain. Examination of flows from 1971 to 2009 indicates that good effort was taken in the collection of water levels. However, within this period data for 5 years is regarded unsatisfactory as much of it was missing. From 1987 to 2009 there is no break in record from which the absolume maximum flows were isolated for this study.

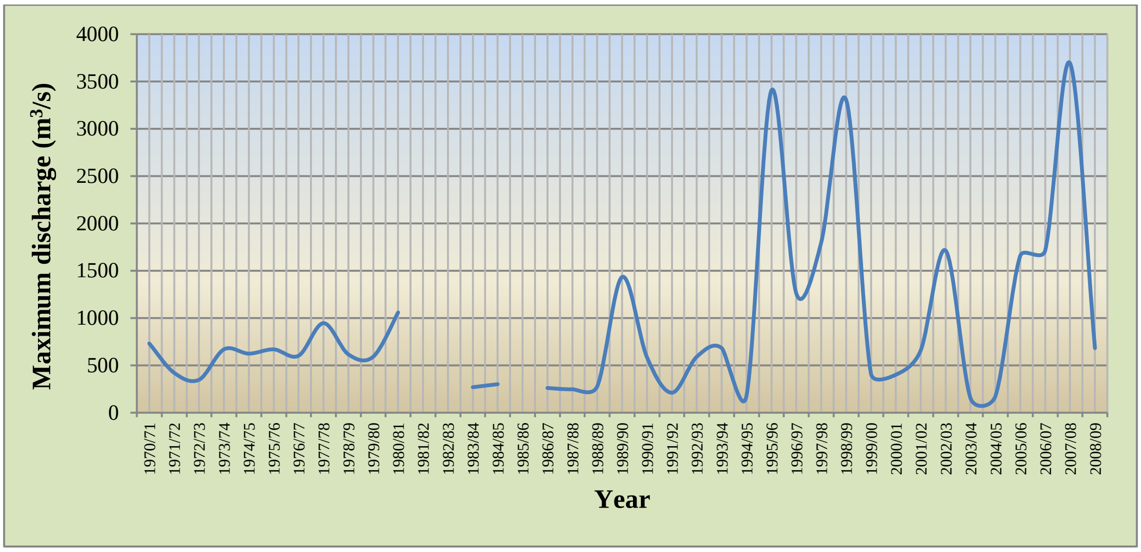

Figure 33: Absolute maximum flows for Linthipe at Salima (1971-2009)

Several extremely high flows are noted and these were over 1,500m^3/s which occurred from 1995 to 2000 with a lower one in 1997 but were also quite high from 2006 to

2008 (Figure 33).

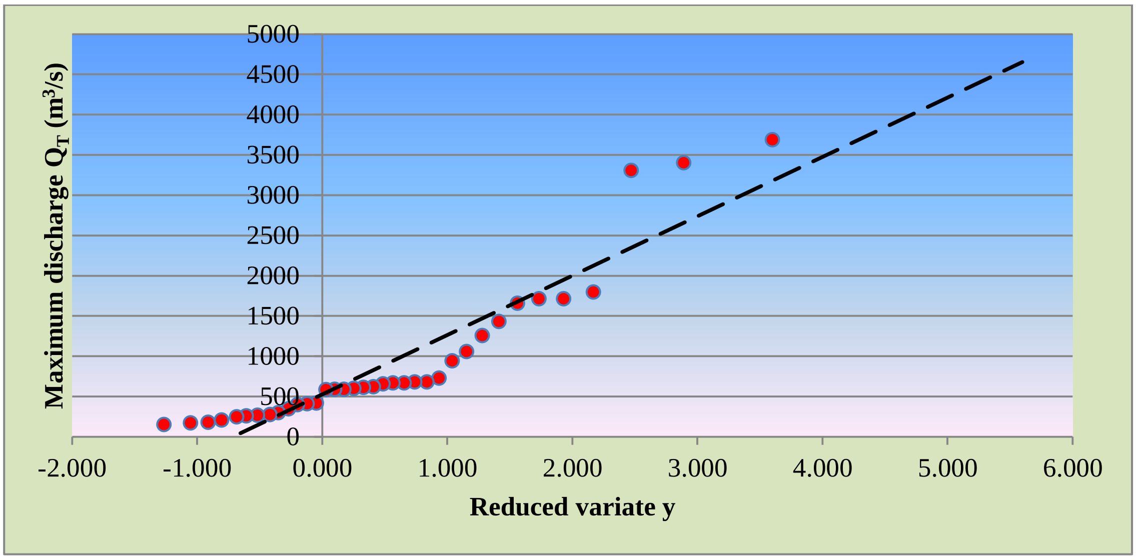

Figure 34: Plot of T-year flood for the Linthipe with its reduced variate y

A quick look at the whole hydrograph depicts one interesting feature which is that there are higher flood magnitudes in the latter part of the period since the station was opened even though this could have been the case during periods of missing data. A plot of the reduced variate y and Q for the Linthipe at Salima produced a satisfactory fit as will be seen in Figure 34. This plot produced a relationship defined by:

$$Q_T = 737.16y + 525.53$$

and had a correlation coefficient R^2 of 0.86

It is evident that during periods when the flow is contained within its channel, the gauge reader is able to take good water level readings seen by the spread of the absolute maximum flows for the station. Since the station is located in a flat area of the lakeshore plain, the riverbed suddenly becomes full of silt and during floods, the channel can no longer contain the whole flow within its banks (Malawi Government, 1986b). During this time the flow inundates a large area and the rating between the water level and the flow becomes distorted. This is why, the flood magnitudes beyond 2,000m^3/s become as outliers in Figure 34.

<u>Linthipe at Linthipe 4.B.3</u>

The station Linthipe at Linthipe is located downstream of the bridge on the M1 Road between Lilongwe and Dedza (Malawi Government, 1986b). The station was opened on December 1, 1957 and maximum flow data is good and continuous from 1971 to 1999 except for two years – from 1980 to 1982. According to the available data, the highest flow within the basin and during the period 1971 to 1999 was about 700m^3/s (See Figure 35).

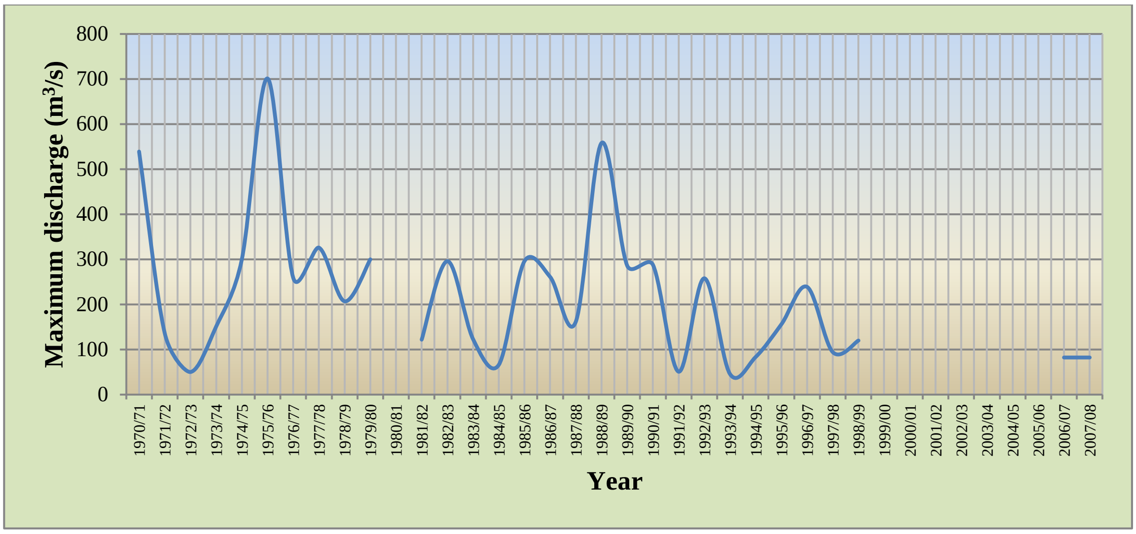

Figure 35: Absolute maximum flows for Linthipe at Linthipe (1971-2008)

A plot of the reduced variate y and Q for the Linthipe at Linthipe produced an exceptionally good fit as will be seen in Figure 36. This plot produced a relationship defined by:

$$Q_T = 129.11y + 145.54$$

and had a correlation coefficient R^2 of 0.93

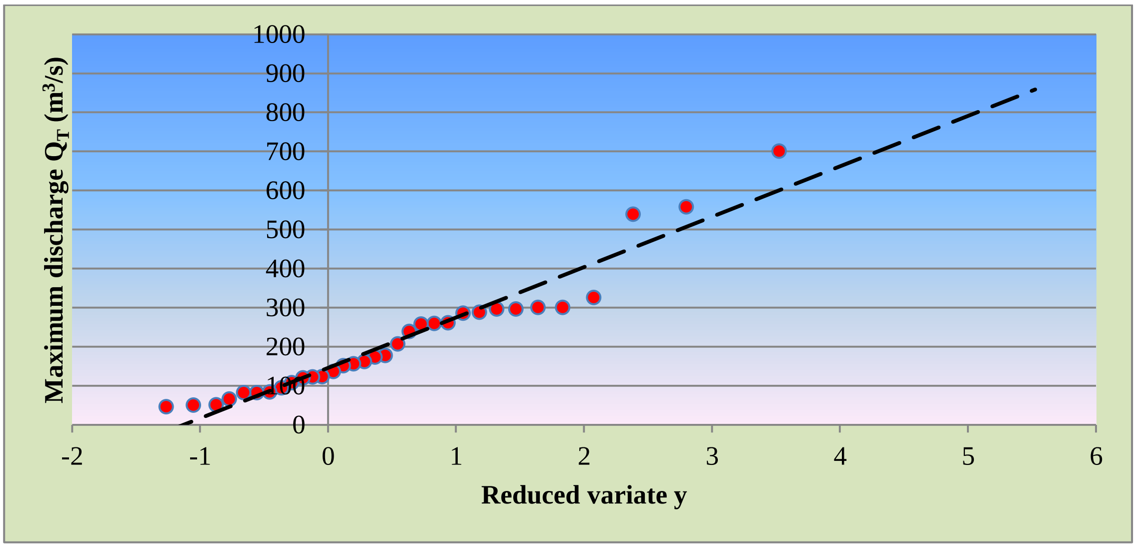

Figure 36: Plot of T-year flood for the Linthipe with its reduced variate y

Despite some visible spread of the plots at high flows between the reduced variates and the discharges, the relationship is strong as evidenced by the high correlation coefficient of 0.93.

Linthipe at Malapa, 4.B.9

Opened on November 27, 1974 (Malawi Government, 1986b) the station is situated a few kilometres above the confluence with the Lilongwe River.

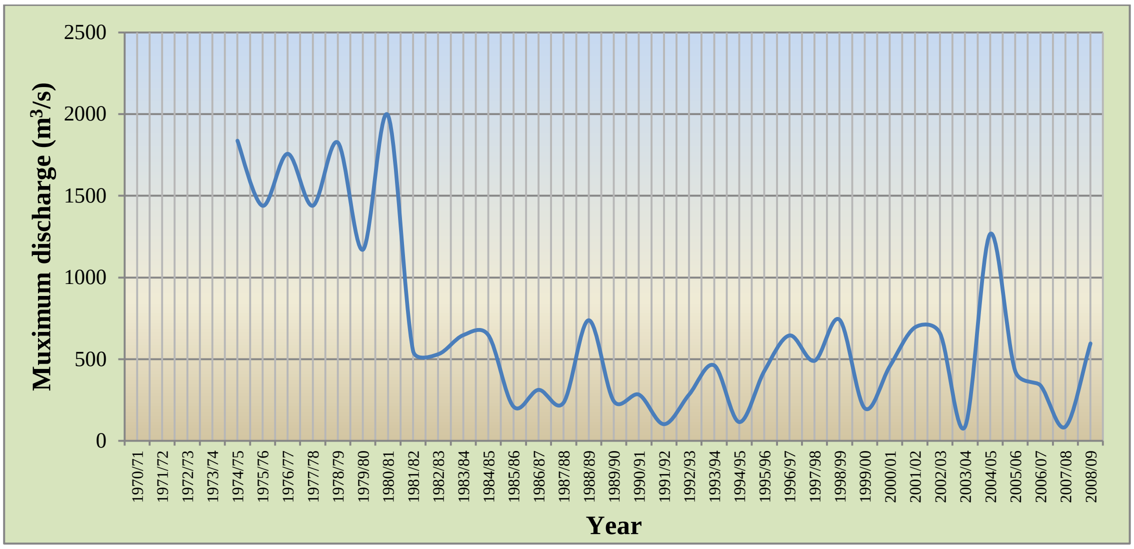

Figure 37: Absolute maximum flows for the Linthipe at Malapa (1971-2009)

At this point the area of the basin above the station is 2,930km^2. From the time the station was opened in 1974 to 2009, it has registered no breakage in data and the wettest year was in 1981 when the flow reached about 2,000m^3/s (See Figure 37). A plot of the reduced variate y and Q for the Linthipe at Malapa produced a reasonably good fit as will be seen in Figure 38. This plot produced a relationship defined by:

$$Q_T = 465.18y + 431.6$$

and had a correlation coefficient R^2 of 0.94

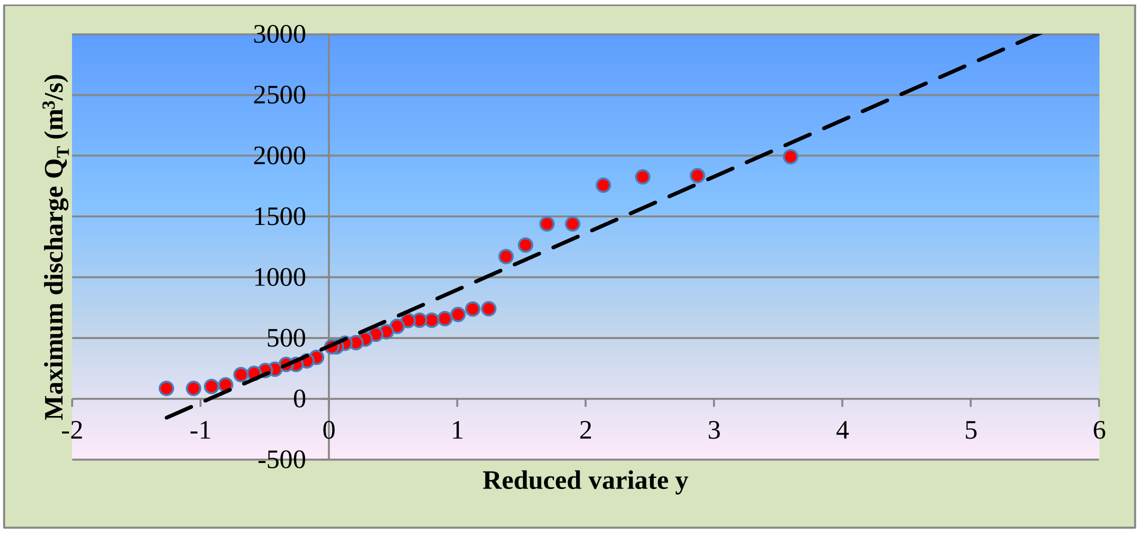

Figure 38: Plot of T-year flood for the Linthipe with its reduced variate y

Both the spread of the plots in Figure 38 and the high correlation coefficient of 0.94 signify good data indicating the dedication of the gauge reader during times of both low and high flows.

<u>Lilongwe at Nkwenembela, 4.C.2</u>

Below the confluence of the Linthipe and the Lilongwe River is another station located at Nkwenembela Village with a RGS No. 4.C.2 that was opened on November 16, 1957 (Malawi Government, 1986b).

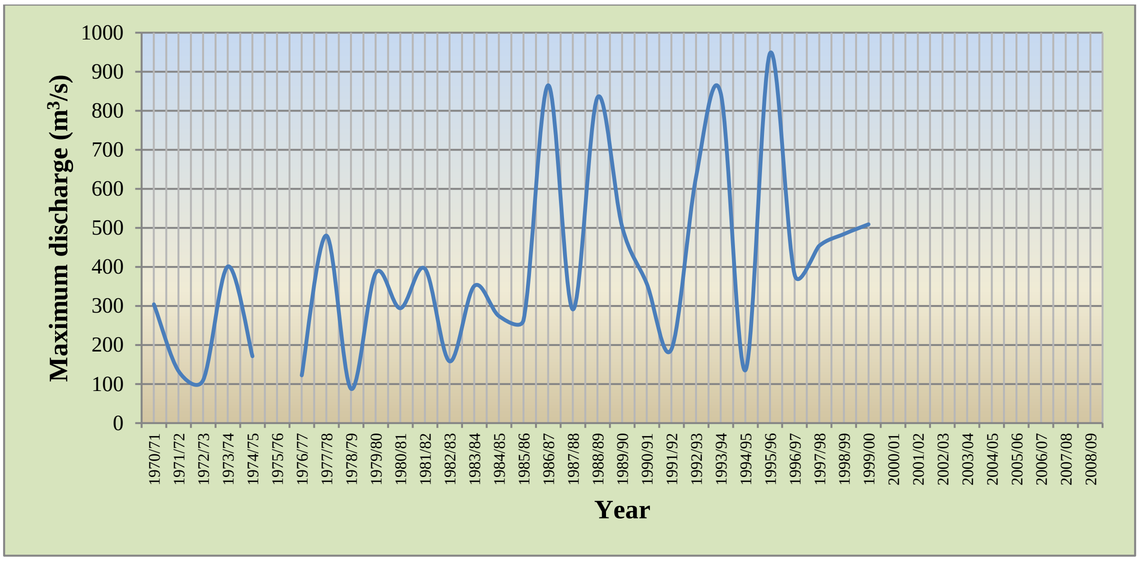

Figure 39: Absolute maximum flows for Lilongwe at Nkwenembela (1971-2000)

According to the classification of stations by the ministry responsible for water affairs, this station is classified as primary and has had an automatic water level recorder for some time. Due to the presence of this facility, the high flows can therefore be regarded as good.

One other interesting fact is that the record is continuous from 1971 to the year 2000 except for two years – 1975 to 1977 (See Figure 39). A plot of the reduced variate y and Q for the Lilongwe at Nkwenembela produced a reasonably good fit as will be seen in Figure 40. This plot produced a relationship defined by:

$$Q_T = 208.18y + 279.65$$

and had a correlation coefficient R^2 of 0.96

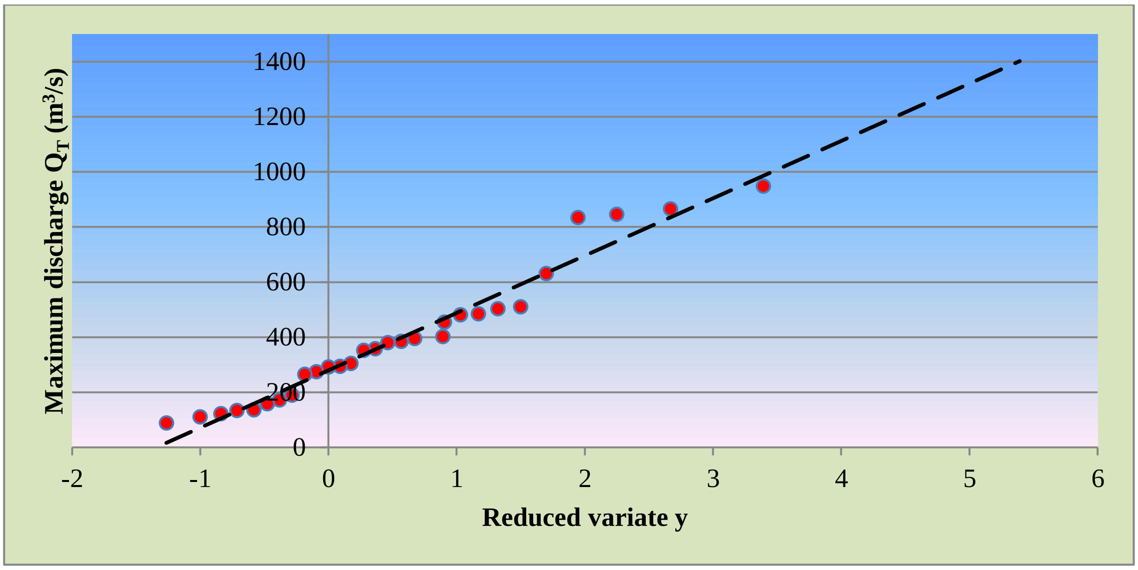

Figure 40: Plot of T-year flood for the Lilongwe with its reduced variate y

The plot of the reduced variates and the discharges in Figure 40 confirms the claim of superior data collected from this station which is also reinforced by the high correlation coefficient.

<u>Lilongwe at Old Town, 4.D.4</u>

Regular Gauging Station No. 4.D.4 was opened on October 21, 1955 (Malawi Government, 1986b) and is located upstream of the road bridge in Old Town. The station has a compound weir with staff gauges and an automatic water level recorder has been here for sometime indicating its primary status. Above this station, the catchment area is 1,870km^2 and the station gauges all the flow originating from the other rivers above it such as Katete and Likuni.

Figure 41: Lilongwe River at Old Town, 4.D.4

Source: Elton Laisi (2014) Regular Gauging Station is located at coordinates 13º 59′ 28″ S. & 33º 46′ 22″ E.

River flow record at this station is satisfactory and it is continuous from 1971 to 2003 even though no data was available for the period from 1996 to 1998. Some notable high flows occurred in 1978 and 1982 with discharges of about 400m^3/s and 375m^3/s respectively. From 2003 to 2009, no record is available or is of poor quality (Figure 42).

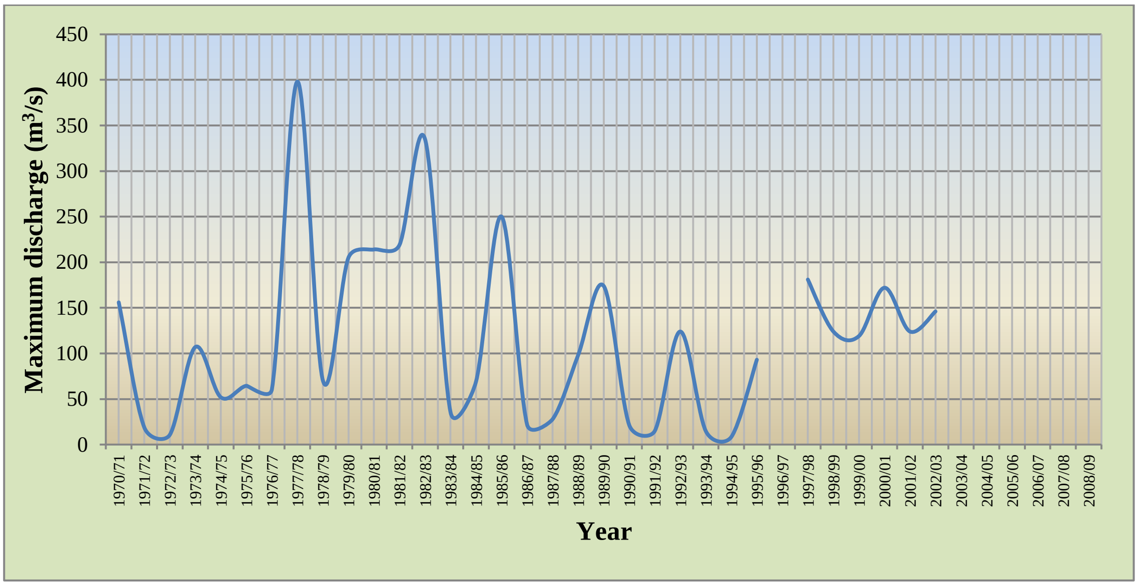

Figure 42: Absolute maximum flows for Lilongwe at Old Town (1971-2003)

A plot of the reduced variate y and Q for the Lilongwe at Old Town produced a reasonably good fit as will be seen in Figure 43. This plot produced a relationship defined by:

$$Q_T = 80.838y + 71.244$$

and had a correlation coefficient R^2 of 0.97

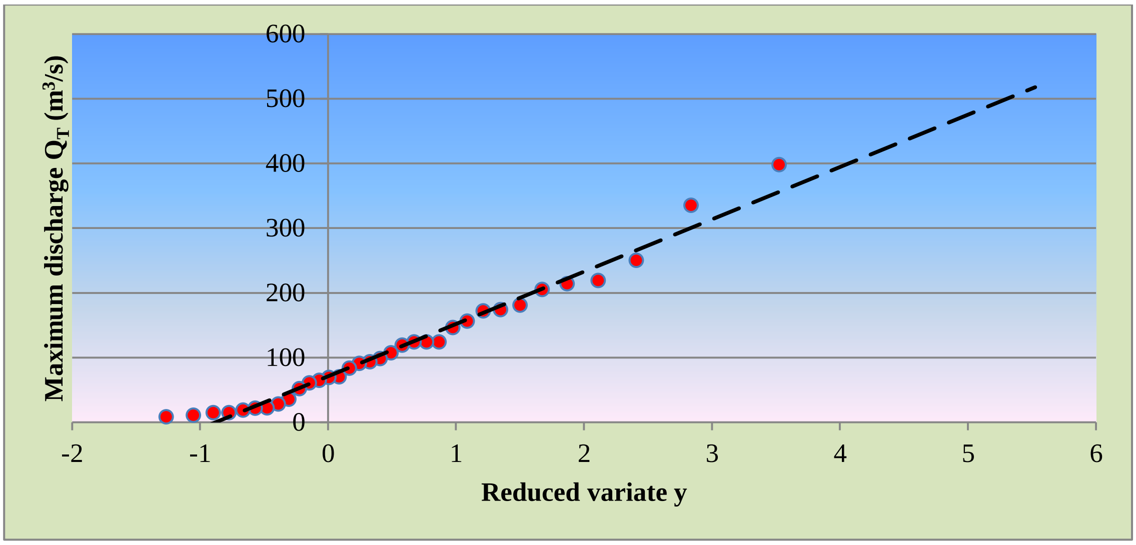

Figure 43: Plot of T-year flood for the Lilongwe with its reduced variate y

The proximity of this station to the main road and the systemmatic collection of water levels has meant that excellent high flow data can be easily captured. This is demonstrated by the good fit of the plot in Figure 43. It must be added however, that the presence of two dams upstream of the station helps in attenuating the floods by the time the flow reaches Malingunde. The spillage and that from tributaries below the two dams is what causes floods in this part of the Lilongwe Basin.

<u>Likuni at Malingunde, 4.D.6</u>

Currently located on the left bank of the Lilongwe River at Malingunde, the station was previously at Sinyala opened on December 23, 1959. The present site was opened below the Kamuzu Dam wall on November 21, 1963 (Malawi Government, 1986b) with manual staff gauges for water level readings. At this point the river basin upstream, has an area of 763km^2 extending into the Dzalanyama Forest on the Mozambican Border. As will be seen from Figure 44, records that can be used are from 1973 to 1990 and the record is continuous with no gaps. After 1990, there is no record for some years or the data is of poor quality.

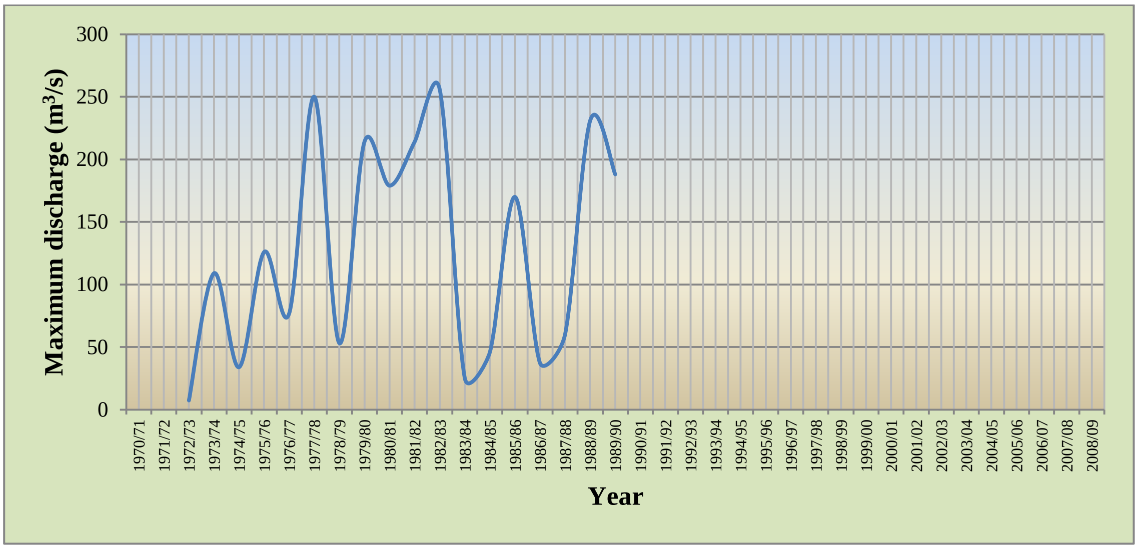

Figure 44: Absolute maximum flows for the Lilongwe at Malingunde (1971-1990)

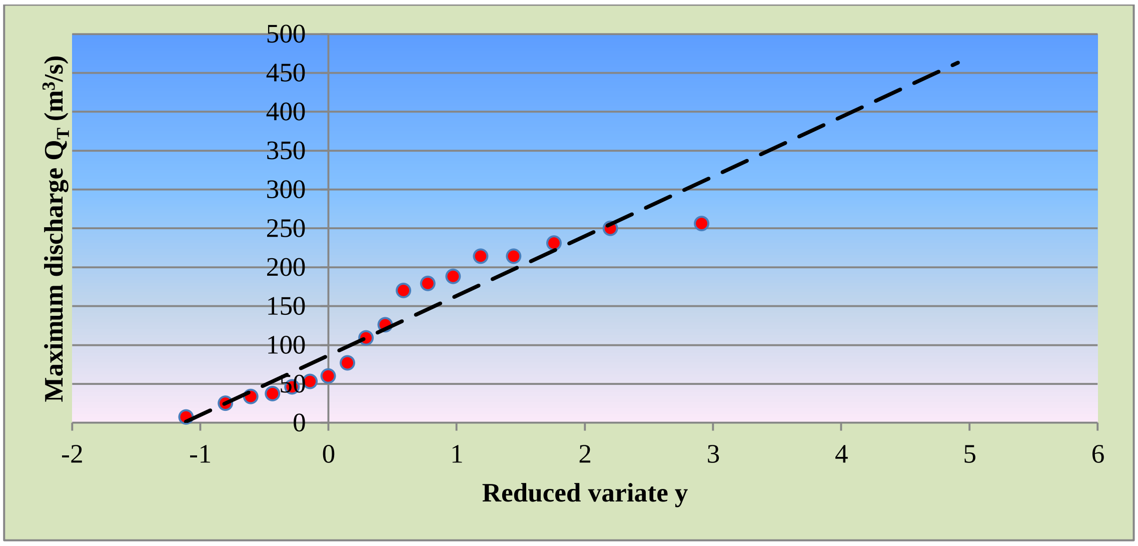

Figure 45: Plot of T-year flood for the Lilongwe with its reduced variate y

A plot of the reduced variate y and Q for the Lilongwe at Malingunde produced a good fit as will be seen in Figure 45. This plot produced a relationship defined by:

$$Q_T = 76.713y + 86.733$$

and had a correlation coefficient R^2 of 0.92

Just like for the Lilongwe River at Old Town, the spread of the points on the plot for the reduced variates and the discharges is good even though this characterisation is not clear above a discharge of 250m^3/s. Nonetheless, a high correlation coefficient of 0.92 gives more confidence on the isolated data for the station.

Lingadzi at M1 Road Bridge, 4.E.1

This station is located in the heart of the City of Lilongwe at a point where the M1 road crosses the river. It was opened on November 18, 1953 and drains an area of 928km^2 that extends into Lilongwe West (Malawi Government, 1986b). Much of the basin is composed of numerous *dambos* with vaguely defined channels and it is only until the main channel becomes defined that the contribution from these *dambos* can be gauged.

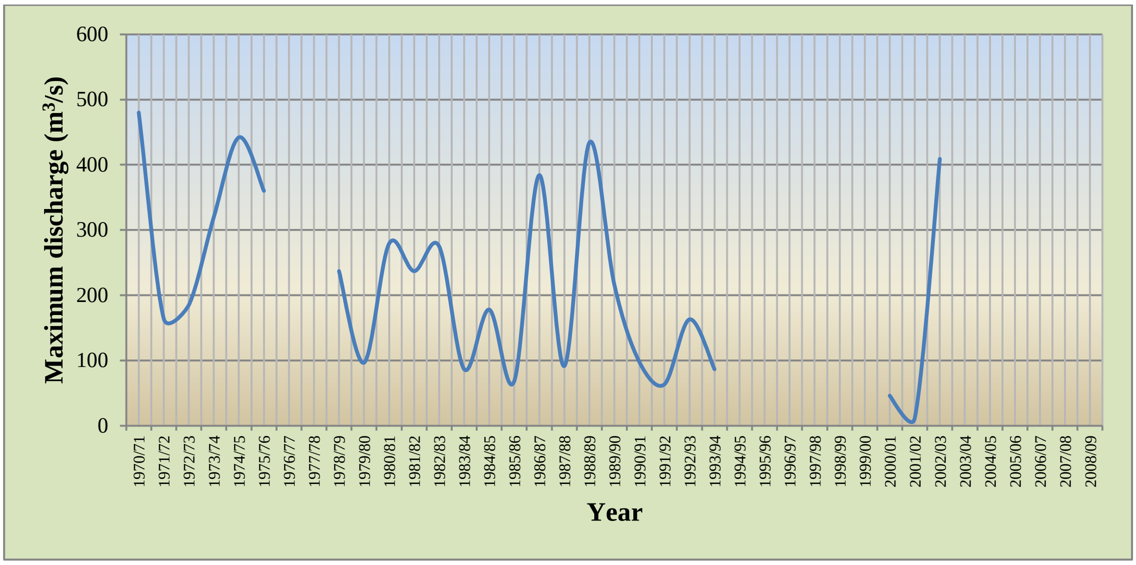

Figure 46: Absolute maximum flows for Lingadzi at M1 Road Bridge (1971-2003)

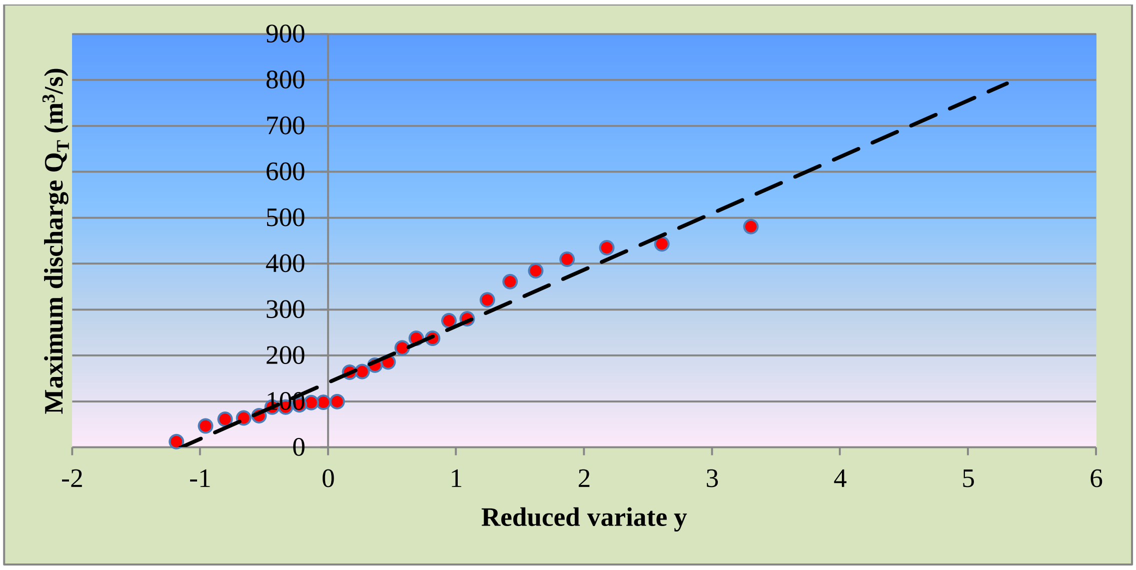

Figure 47: Plot of T-year flood for the Lingadzi with its reduced variate y

From 1971 to 1976 data is available but a big gap of three years occurs. This is followed by another relatively long period of continuous data that defines the flow hydrograph from 1979 to 1994 upon which year there is another long break of no data or data of poor quality until 2001. Little information is available from 2003 until todate

(See Figure 46).

A plot of the reduced variate y and Q for the Lingadzi at M1 Road Bridge produced a yet another good fit as will be seen in Figure 47. This plot produced a relationship defined by:

$$Q_T = 122.77y + 140.77$$

and had a correlation coefficient R^2 of 0.96

Despite the gaps in the records of absolute maximum flows, the data is good and has been used in this study. A correlation coefficient of 0.96 for this station is high enough to provide confidence on the quality of data. This is due to the fact that the bridge on the M1 road has both acted as a control for high flows and has also provided a good platform from which to take discharge measurements at high flows.

Lingadzi at S11 Road Bridge, 4.E.2

The station is several kilometres upstream of 4.E.1 and was opened in December 1969 with only two 5-foot imperial gauges which were later replaced by metric gauges on March 17, 1983. According to the ministry responsible for water affairs, the stage/discharge relationship is good throughout the range of water levels (Malawi Government, 1986b). Absolute maximum flows are continous from 1971 to 1999 when the record stops. No gaps exist throughout this period with 1996 and 1998 registering the highest flows from the available record as can be seen in Figure 48.

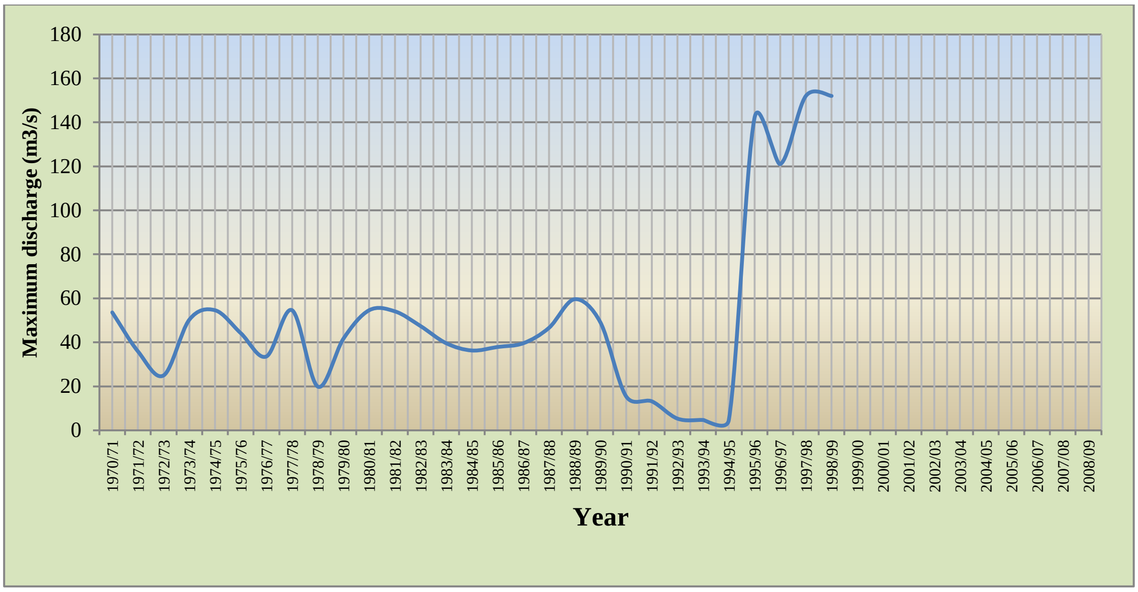

Figure 48: Absolute maximum flows for Lingadzi at S11 Road Bridge (1971-1999)

A plot of the reduced variate y and Q for the Lingadzi at S11 Road Bridge produced a reasonably good fit as will be seen in Figure 49. This plot produced a relationship defined by:

$$Q_T = 32.706y + 33.176$$

and had a correlation coefficient R^2 of 0.86

However, it can still be seen from Figure 49 that despite the positive view about flows throughout the range of water levels being good as claimed by findings in earlier studies (Malawi Government 1986b), there is difficulty in gauging flows above 50m^3/s. This could be due to poor water level readings or absence of a suitable platform for gauging high flows during times of floods.

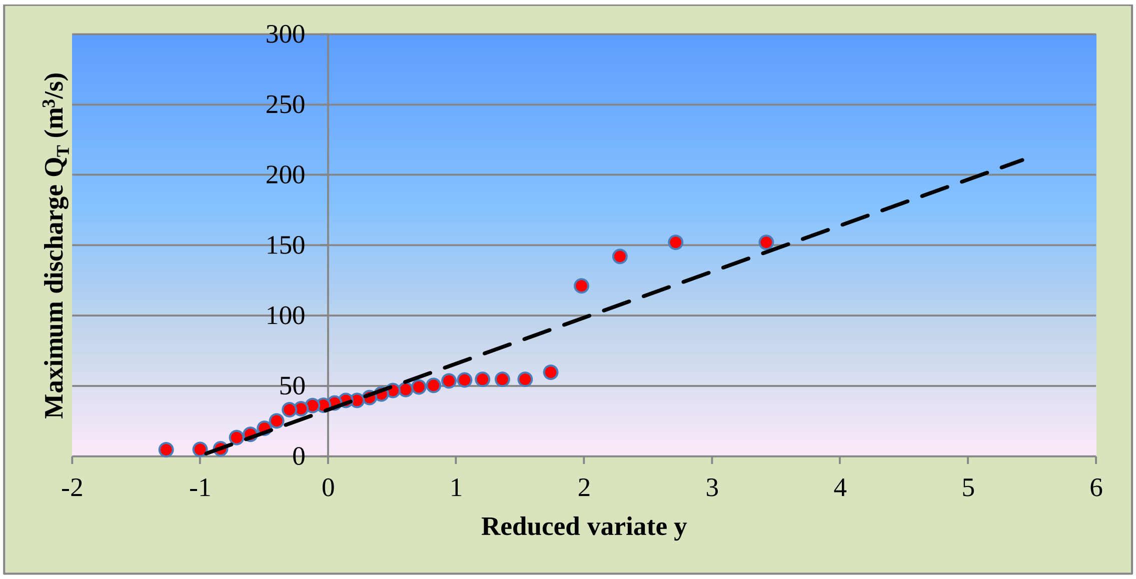

Figure 49: Plot of T-year flood for the Lingadzi with its reduced variate y

<u>Lumbadzi at Simakuni, 4.F.6</u>

The Lumbadzi River drains much of the Dowa Hills and flows in a south-easterly direction to pour its waters into the Lilongwe River below Simakuni Village. The gauging station 4.D.6 was opened at this village on November 30, 1974 (Malawi Government, 1986b) consisting of metric gauges up to 4.5 metres.

During the first few years records were poor up to 1978 despite having a low level bridge from where discharge measurements could be taken for medium to high flows. However, there was marked improvement in data collection from 1978 to 1996 when no gaps exist in flood flows.

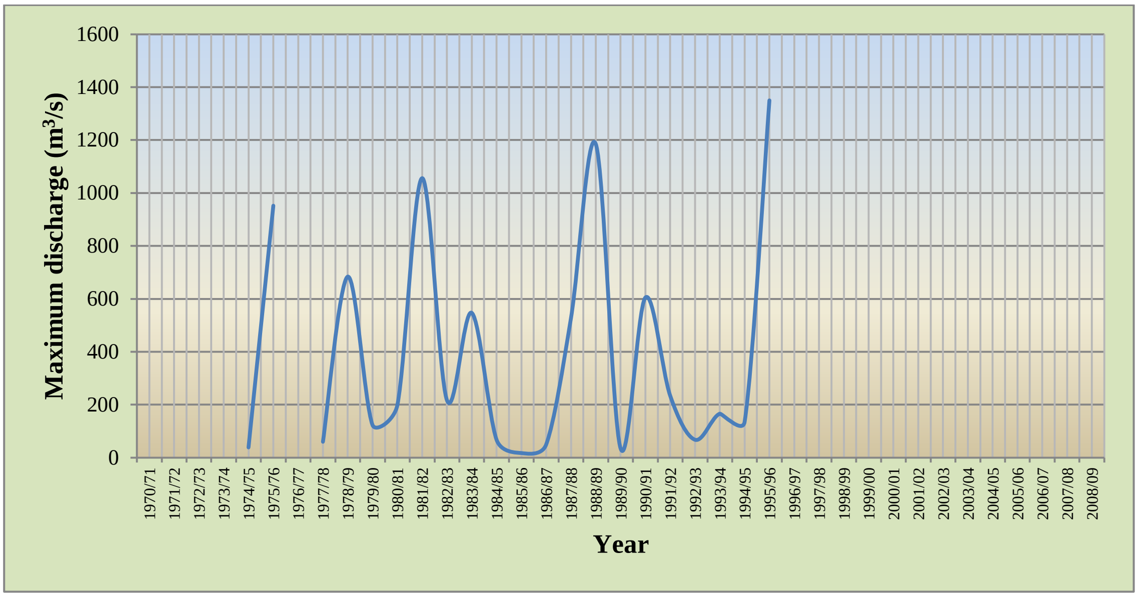

Figure 50: Absolute maximum flows for Lumbadzi at Simakuni (1971-1996)

The highest flows at the station which has a total catchment area of 449km^2 were in 1982, 1989 and 1996 with flows of about 1050m^3/s, 1,200m^3/s and 1,350m^3/s, respectively (See Figure 50).

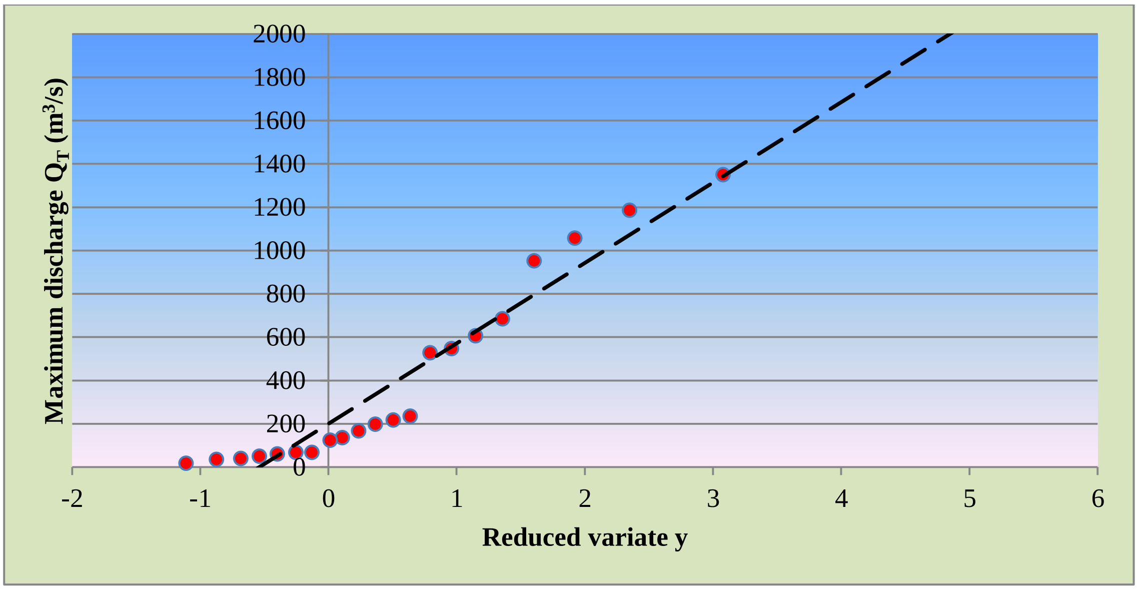

Figure 51: Plot of T-year flood for the Lumbadzi and its reduced variate y

A plot of the reduced variate y and Q for the Lumbadzi at Simakuni produced a reasonably good fit as will be seen in Figure 51. This plot produced a relationship defined by:

$$Q_T = 371.37y + 199.84$$

and had a correlation coefficient R^2 of 0.92

Although there is no data for the early years of this station, the plot of the reduced variates and discharges is quite good even at high flows as will be seen in Figure 51. Therefore the results of the analysis for this station can be used with much confidence as strengthened by the high correlation coefficient.

Floods have also caused havoc within the Linthipe River Basin. In January 2001 a small tributary of the Linthipe, the Tete burst its banks and flooded a large area in TA Kaphuka's area in Dedza District. During this time 106 households had their gardens and crops washed away leaving them destitutes for the next season and heavily relying on assistance from government and aid agencies for food and other requirements. During the same month 120 households in TA Chitukula's area had their houses destroyed and 34 hectares of crops were washed away (Willy and Partners Engineering Services, 2005). Serious flooding was also observed on January 4, 2003 when Lilongwe River including the Linthipe and Lifidzi could not contain their waters within the confines of the channel. During this time, 3,000 households had their houses damaged while 24, 568 households had their crops washed away by the floods.

Bua River Basin

The Bua River Basin starts from the Dzalanyama Range on the border with Mozambique to the west and while being extensive and wide in this upper reach, it gradually becomes narrow on its way towards the lake to the east. Rusa and Mtiti River Basins are located within this basin. The Bua River Basin is densely covered by vast *dambos* which are wet areas even in the dry season within which dry season cultivation may be found practiced by many people living within the basin. These *dambos* become marshy during the wet season particularly in the Rusa River Basin and can be quite expansive. As the Bua River flows over and beyond the Escarpment Zone, it passes through rugged terrain of narrow gorges with potential for hydropower generation. However, in its upper reaches, the basin is extensively flat and cultivated save for the lower parts which are covered by the Nkhotakota Game Reserve.

Several regular gauging stations were opened within the basin particularly in the upper and lower reaches of the river and its tributaries. Much of the central portion of the basin has no stations because of the dominance of dambos where there are no clearly defined channels. In the upper reaches of the basin, the rivers that have regular gauging stations are the Namitete, the headwaters of the Bua, and Liwelezi. Below this part in the middle of the basin, four stations are located on the main channel of the Bua and one on Mtiti. Of these rivers, those that were selected for this study and their existing river gauging stations are (Malawi Government, 1986b):

- Bua at S53 Road Bridge, RGS 5.C.1;
- Mtiti at Mtiti, 5.D.3; and
- Rusa at Kasela, 5.F.1.

All the three stations are located in the area below the confluence of the Rusa with the Bua River. Absolute maximum flows were isolated from available data and plotted against their year of occurrence for all the three gauging stations as has been done for those in the South-Western Lakeshore Basin and the Linthipe Basin. These are discussed below.

Bua at S53 Road Bridge, RGS 5.C.1

Regular gauging station 5.C.1 opened in October 1956 (Malawi Government, 1986b) is located at the bridge on the lakeshore road and had a cableway from where high flows are gauged. At this point, the area above the station is 10,600km^2 making this station one of those with the largest catchment area for which flow is measured. The upper part of the basin is densely populated covering the districts of Mchinji, Lilongwe, Kasungu, Dowa and Ntchisi but becomes sparsely populated in the lower reaches especially where it is occupied by the Nkhotakota Game Reserve.

Examination of the hydrograph for the absolute maximum flows (See Figure 52) shows excellent continuous record from 1971 to 2003 when the record breaks until 2006. From 2006 there is some record up to 2009. Highest flows of above 1,000m^3/s were observed in 1973, 1985, 1990 and 1999 with flows of 1,700m^3/s, 1,090m^3/s, 1,400m^3/s and 1,040m^3/s respectively.

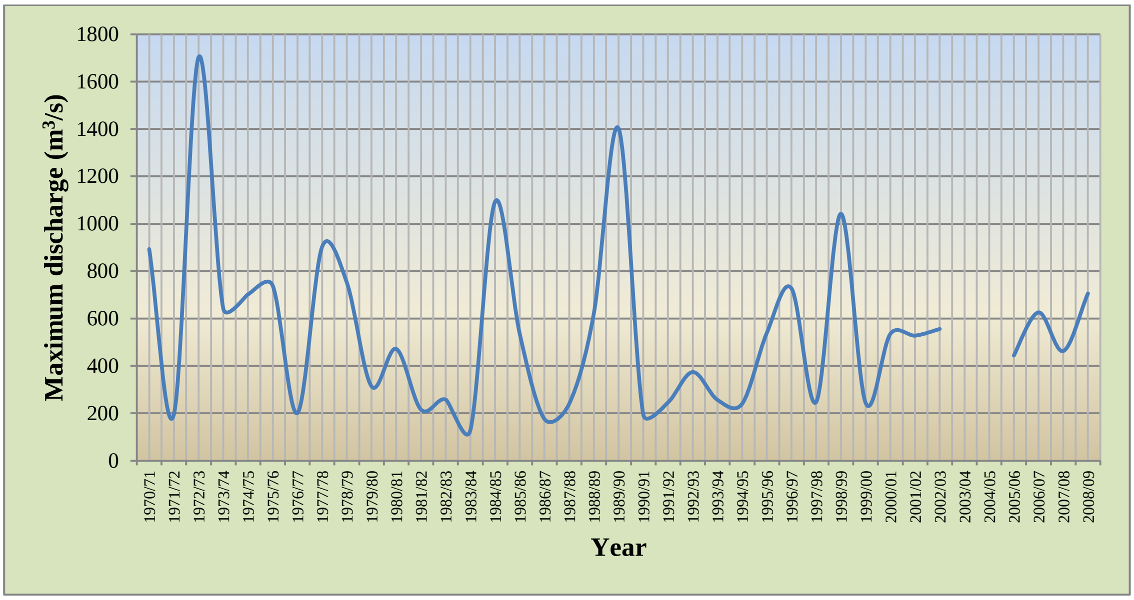

Figure 52: Absolute maximum flows for Bua at Bua Drift (1971-2009)

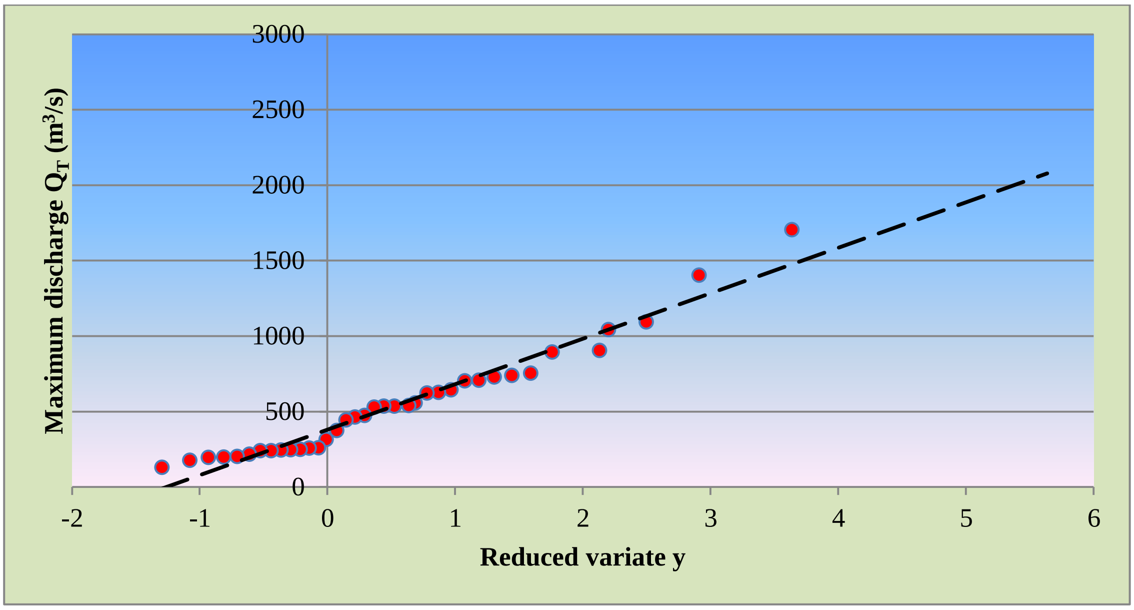

Figure 53: Plot of T-year flood for the Bua and its reduced variate y

A plot of the reduced variate y and Q for the Bua at Bua Drift produced a good fit as will be seen in Figure 53. This plot produced a relationship defined by:

$$Q_T = 301.25y + 379.92$$

and had a correlation coefficient R^2 of 0.96

This excellent relationship must be due to the availability of regular measurements from the station by use of the cable car and the water level recorder stationed on the right bank of the channel. Low absolute maximum flows including those in the medium and high range produce a good fit for the flood flows with their reduced variates.

Mtiti at Mtiti, 5.D.3

Station 5.D.3 was opened in 1955 (Malawi Government, 1986b) even though it is not clear where exactly it was located. The present site which is located downstream of the M1 Road Bridge at Mtiti Trading Centre was opened in 1958 with the control being provided by a 90º V-notch. At this point the total area above the station is 233km^2.

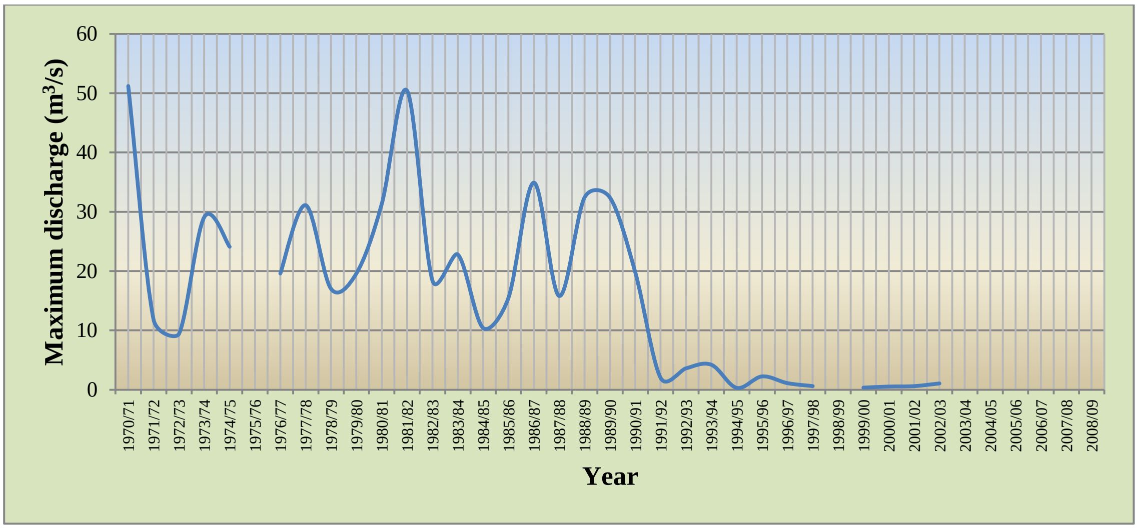

Figure 54: Absolute maximum flows for Mtiti at Mtiti (1971-2003)

The absolute maximum flow hydrograph for the station indicates continuous data collection from 1971 to 2003 with two breaks between 1975 to 1977 and 1998 to 2000. While other high flow magnitudes are hidden by this break in data collection, the only visible highest flow was in 1982 when the flow was slightly greater than 50m^3/s (See Figure 54). The flood that destroyed the bridge in 2003 was not captured as that is the same year when water levels and flows stopped probably indicating that the flood had removed the staff gauges all together.

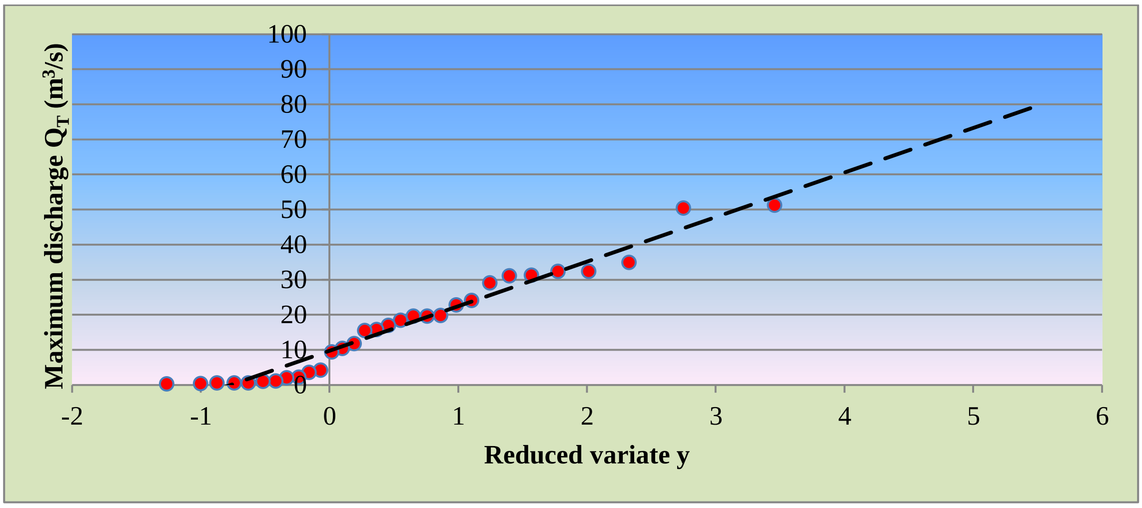

Figure 55: Plot of T-year flood for the Mtiti and its reduced variate y

A plot of the reduced variate y and Q for the Mtiti at Mtiti produced a good fit as will be seen in Figure 55. This plot produced a relationship defined by:

$$Q_T = 12.701y + 9.757$$

and had a correlation coefficient R^2 of 0.96

Rusa at Kasela, 5.F.1

This station is situated about 2km above the confluence with the Bua River at Kasela Village and was opened in 1957 as a miscellaneous gauging station. It graduated to a full RGS in 1964 and has a drainage area of 2,580km^2.

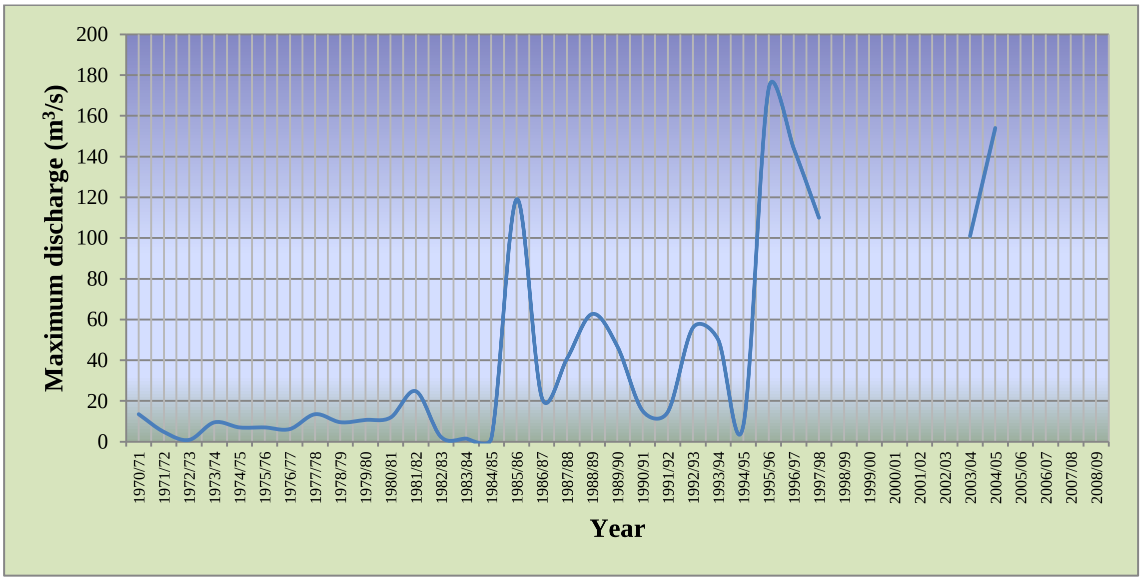

Figure 56: Absolute maximum flows for Rusa at Kasela (1971-2005)

According to the ministry responsible for water affairs (Malawi Government, 1986b), the station has faced two challenges in its operation. Firstly, the control at the station becomes submerged during times of high flows and secondly people around the area disturb the water level/discharge relationship due to placement of fishing nets around it. Nonetheless cross examination of flows with those of the Bua at RGS 5.D.2 indicate that the flows at Kasela are good (Figure 56).

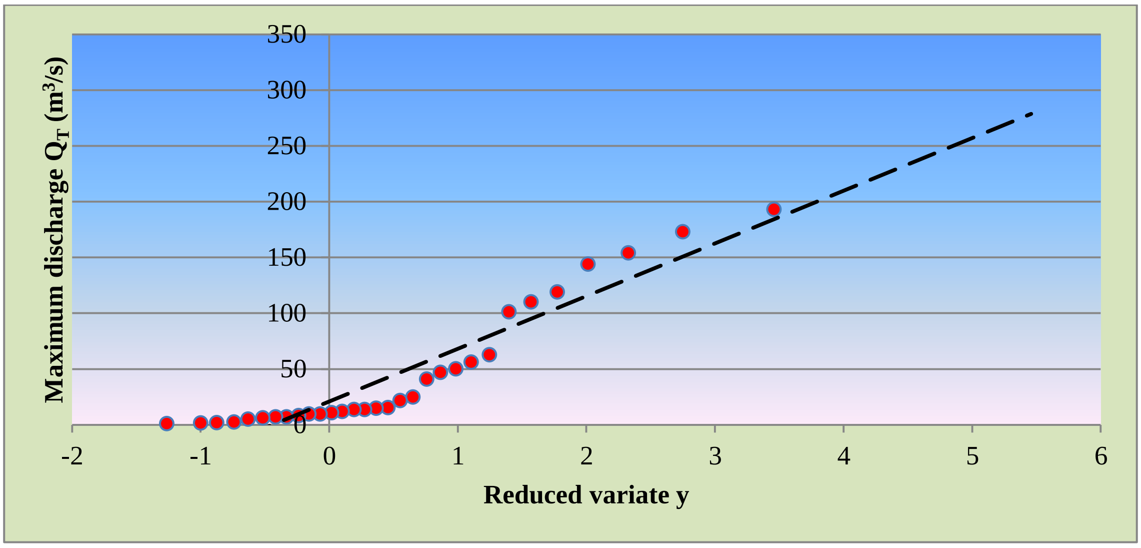

Figure 57: Plot of T-year flood for the Rusa and its reduced variate y

A plot of the reduced variate y and Q for the Rusa at Kasela produced a satisfactory fit as will be seen in Figure 57. This plot produced a relationship defined by the relationship:

$$Q_T = 47.221y + 20.98$$

and had a correlation coefficient R^2 of 0.89

Judging from the relatively low correlation coefficient obtained for this station as compared with other stations under this study, this confirms the ineffectiveness of the control at the station during periods of high flows. As will be seen from Figure 56, water level and flow data are easily collected during the dry season while it becomes difficult during the wet season and is further complicated by the ineffectiveness of the control at high stages.

The Bua River Basin is also prone to flooding. In January 2001, the headwaters of the Bua River caused extensive flooding in the areas of TAs Dambe, Mkanda, Mlonyeni and Zulu and STAs Kapondo, Nduwa, Mavwere and Simphasi in Mchinji District where 2,000 households were affected with high water levels in their areas. This caused a lot of suffering especially in terms of food, accommodation and sanitation. This incident was repeated in February 2003 and 2,052 households had damaged houses with 1,586 households having lost their crops.

The hydrograph in Figure 56 seems also to agree with what respondents said for Rusa that there was a big flood in 2006. On January 3, 2003 a number of spontaneous floods also occurred within the basin and the most significant flood occurred within the Mtiti River Basin. The Mtiti River burst its banks after many years and the Mtiti Bridge on the M1 Road was swept away. In Nkhotakota District, 97 households in TA Mphonde's area had their houses damaged and 213 hactares of crops were washed away affecting 1,113 households.

Dwangwa River Basin

The Dwangwa River Basin shares its sourthern border with the Bua River Basin. To the west is the Kasungu National Park, a well-vegetated flat plain consisting mainly of indigenous woodlands and white sandy soils. The northern frontier of the basin is marked by the headwaters of the numerous streams that drain the southern foothills of the Viphya Plateau. As the main river, the Dwangwa flows eastwards, it passes through a terrain of gentle slopes before abruptly falling over the Escarpment Zone on its way to the lake. Much of the middle and lower parts of this basin are well vegetated with indigenous forests.

The major rivers in this basin are the Liziwazi, Mpangala, Lingadzi, Chitete, Livwezi, Liwala, Kangwa, Lilavwa, Mlozi, Mpasadzi, Milenje, Liwelezi, Phazi and the Rupache (Malawi Government, 1986b). Many of these rivers flow during the wet season only even though during years of high precipitation, they are able to trickle throughout the year. Two stations with RGSs were selected from this river basin and these are:

- Dwangwa at Dwangwa, RGS 6.C.1; and
- Mpasadzi at M1 Road Bridge, 6.C.5.

The two stations lie in an area of undulating terrain and measure flows draining much of Kasungu District and the southern slopes of the Viphya Plateau in Mzimba District of the Northern Region.

Dwangwa at Dwangwa, RGS 6.C.1

The station is situated a few metres upstream of the M1 road bridge on the Lilongwe – Mzimba Road and was opened in February, 1953 (Malawi Government, 1986b) with a compound rectangular weir as the control. For a long time, the station has had a cable car for measuring discharges at high water levels and an automatic water level recorder to assist in measuring gauge heights.

From 1971 to 2009 the station has provided high quality data that has enabled the production of absolute maximum flow hydrograph as seen in Figure 58. Throughout this period, flood flows have been ably captured mainly through the presence of the water level recorder and the cable car and data only misses between1996 and 1998 and also between 2003 and 2007.

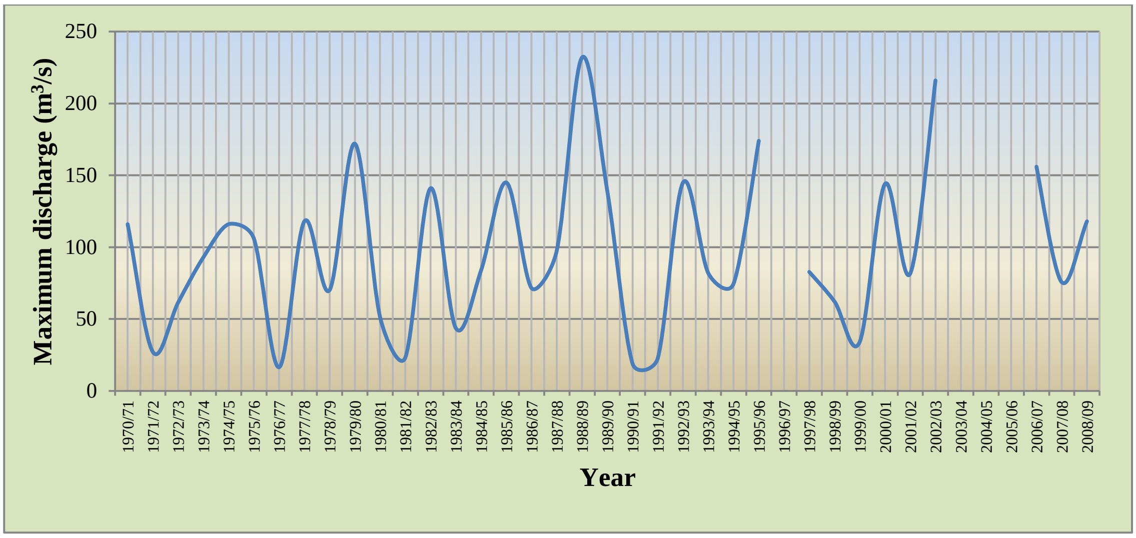

Figure 58: Absolute maximum flows for Dwangwa at Khwengwele (1971-2009)

Observed highest flows of the absolute maxima with discharges of more than 150m^3/s occurred in 1980, 1989, 1996, 2003 and 2007 with flows of 172m^3/s, 232m^3/s, 174m^3/s, 216m^3/s and 156m^3/s respectively.

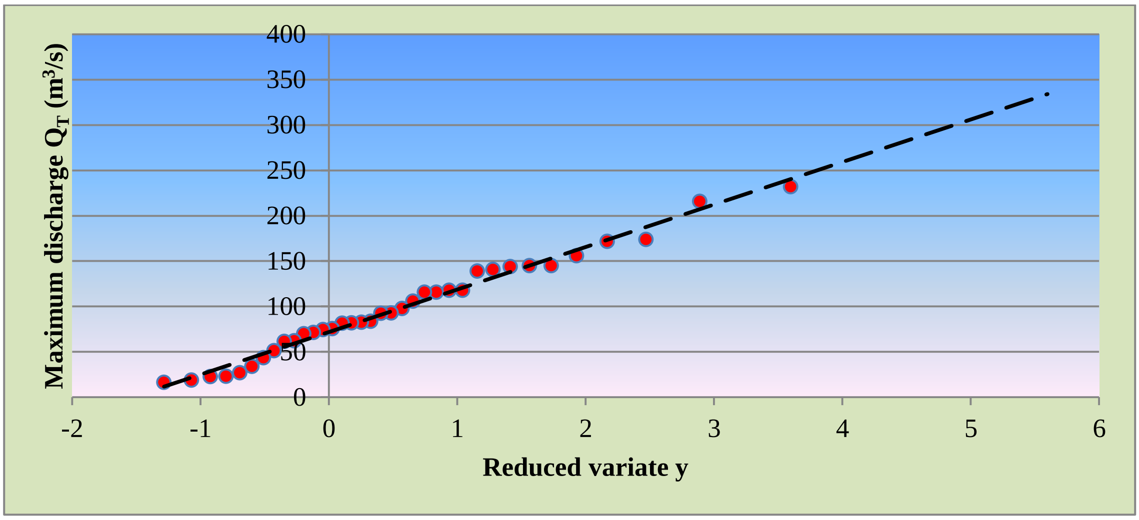

Figure 59: Plot of T-year flood for the Dwangwa and its reduced variate y

A plot of the reduced variate y and Q for the Dwangwa at Khwengwele produced an excellent fit as will be seen in Figure 59. This plot produced a relationship defined by:

$$Q_T = 46.807y + 72.026$$

and had a correlation coefficient R^2 of 0.98

This station produced the highest correlation coefficient of 0.98 among all the stations considered in this study depicting the high quality of the data that has so far been collected from this site.

<u>Mpasadzi at M1 Road Bridge, 6.C.5</u>

This station drains an area of 309 km^2 and was opened on November 12, 1965 (Malawi Government, 1986b). The channel itself has acted as the control at the station and data is of good quality for low and medium levels. Due to the absence of a cable car, it has not been possible to measure exceptionally high stages during flood periods. Save for the period 1977 to 1980, the record of high flows is continuous.

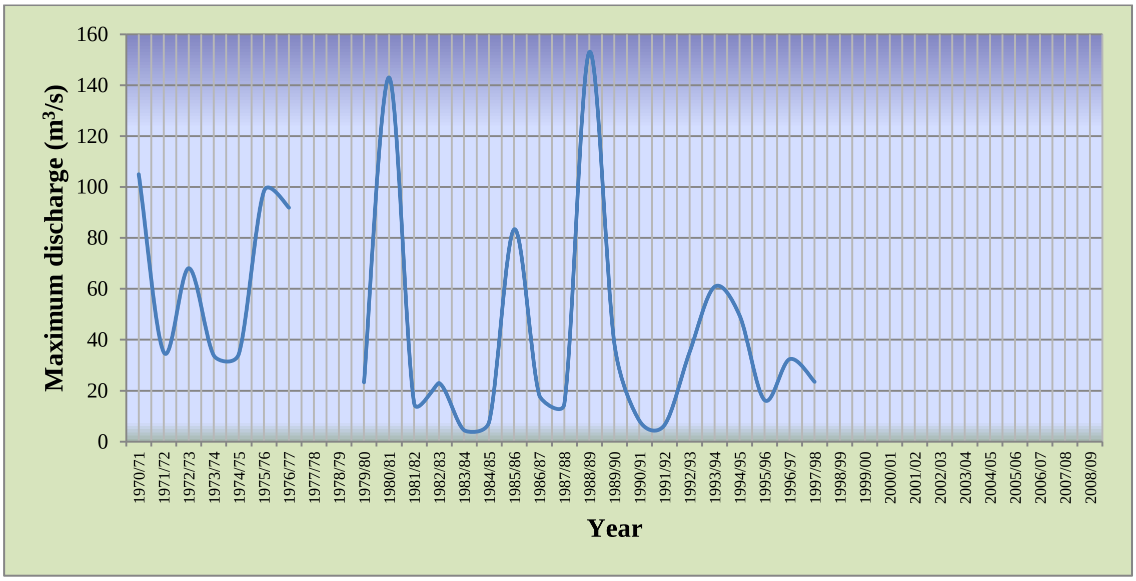

Figure 60: Absolute maximum flows for Mpasadzi at M1 Rd. Bridge (1971-1998)

The highest flows were recorded in 1981 and 1989 with magnitudes in excess of $140 m^3/s$ (See Figure 60).

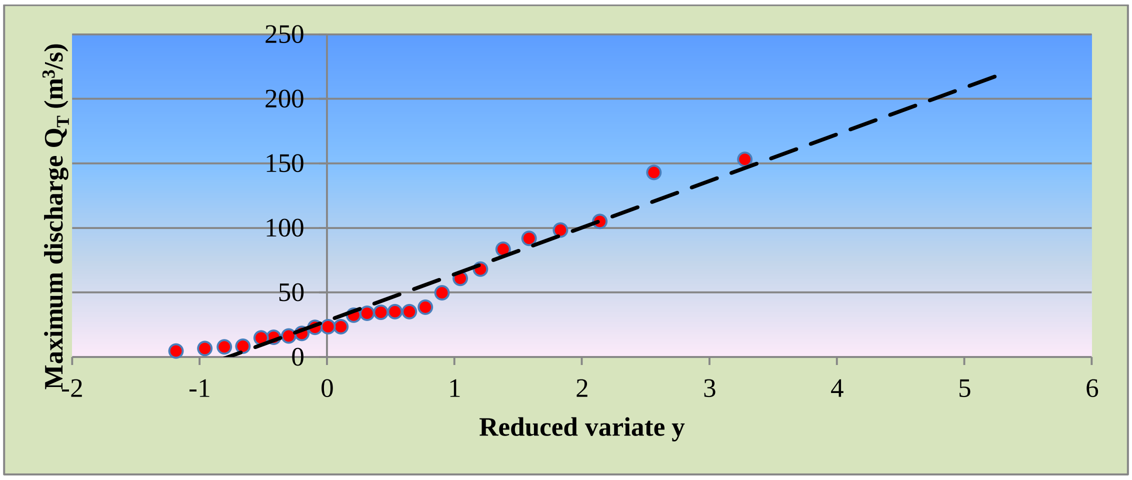

Figure 61: Plot of T-year flood for the Mpasadzi and its reduced variate y

A plot of the reduced variate y and Q for the Mpasadzi at M1 Road Bridge produced a good fit as will be seen in Figure 61. This plot produced a relationship defined by:

$$Q_T = 36.15y + 27.846$$

and had a correlation coefficient R^2 of 0.94

Despite having no high flow measuring facility, the spread of the plots for the reduced variates and their dischrges shows an excellent relation. The floods of March 2001 in TA Kaomba's area in Kasungu District affected many people within the upper reaches of the basin. About 1, 440 people were affected and of these, some had their houses damaged and others had their crops washed away. During years of high flows resulting from intense precipitation, the Dwangwa River can be a menace to the Illovo Sugar Estate at Dwangwa Trading Centre on the shores of Lake Malawi.

River Basins of the Lakeshore Plain

This is a flat region that extends from Salima to the south to as far north as Dwambazi River which forms the norther boundary of the Central and Northern regions of the country. The lakeshore plain is generally flat from south to north lying parallel to the west of the lake except in the central parts where it is broken and rugged. The soils in the region are of various formations consisting of exceptionally fertile alluvials, lithosols, and hydromorphics.

The major rivers within this basin are the Lipimbi, Lingadzi, Chirua, Luwazi, Lifidzi, Nkula, Lifuliza, Likoa and Kaombe (Malawi Government 1986c). Numerous other streams flow within the basin in a west-easterly direction to pour their waters into Lake Malawi. However, the majority of these streams and other major rivers mentioned above, are rarely perennial due to the soil types and so the flow from the plateau regions of Dowa and Ntchisi disappears into the loose sands of the lakeshore plain. Of these rivers, those that are selected for this study and their existing river gauging stations (RGS) are:

- Chirua at Matambe, RGS 15.A.4;
- Lingadzi at Kaniche, 15.A.8; and
- Kaombe at Chanika, 15.B.13.

Chirua at Matambe, RGS 15.A.4

Located in what may be termed the receiving area, the flows of the three rivers of Chirua, Lingadzi and Kaombe like the others on the lakeshore plain are influenced by weather conditions over the plateau of the central region as well as local weather conditions. A heavy storm over the plateau can cause a huge flood in these areas with maximum basin flow concentration just like local weather conditions could also influence flooding.

The rivers are located in areas of high soil erosion due to the high erosivity of the alluvials and hydromorphic soils and therefore construction of hydraulic structures have to take this into account. This station was opened in November 1957 about 1.6km upstream of the S33 Road (Malawi Government 1986c), now commonly known as the Lakeshore Road. Due to excessive siltation, it was moved to the present site at the Road Bridge on the Lakeshore Road. For the whole period from 1971 to 2000 the station has had a long period of missing or poor data as is the case from 1975 to 1986. However, data is available for the period 1971 to 1975 and from 1986 to 2000. The highest flows have been observed in recent times especially from 1988 to 2000 (See Figure 62).

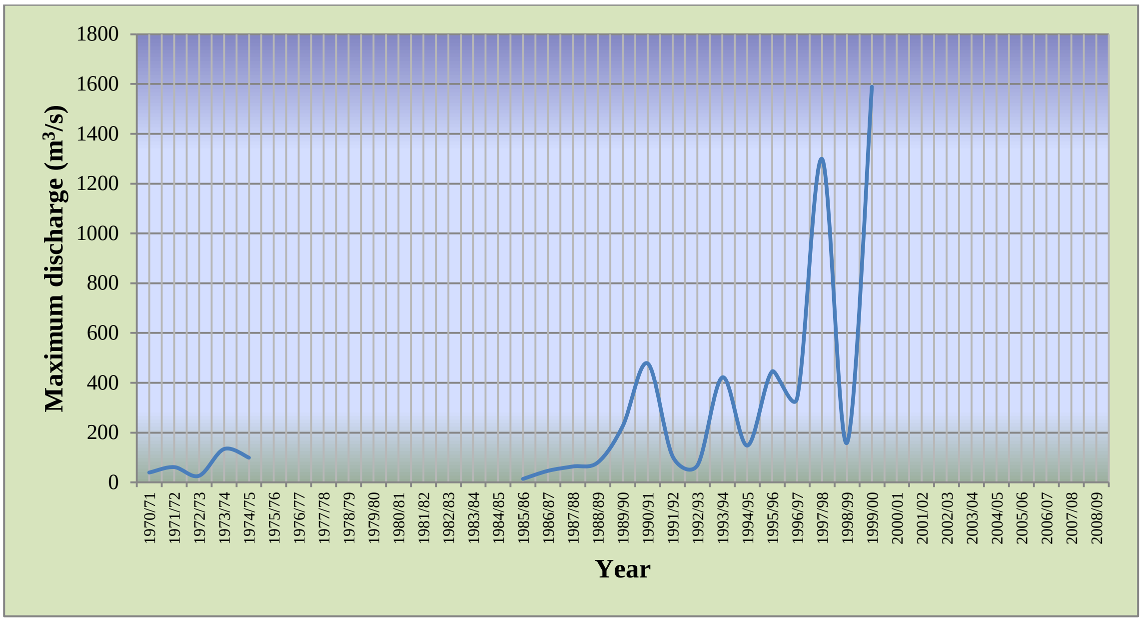

Figure 62: Absolute maximum flows for Chirua at Matambe (1971-2000)

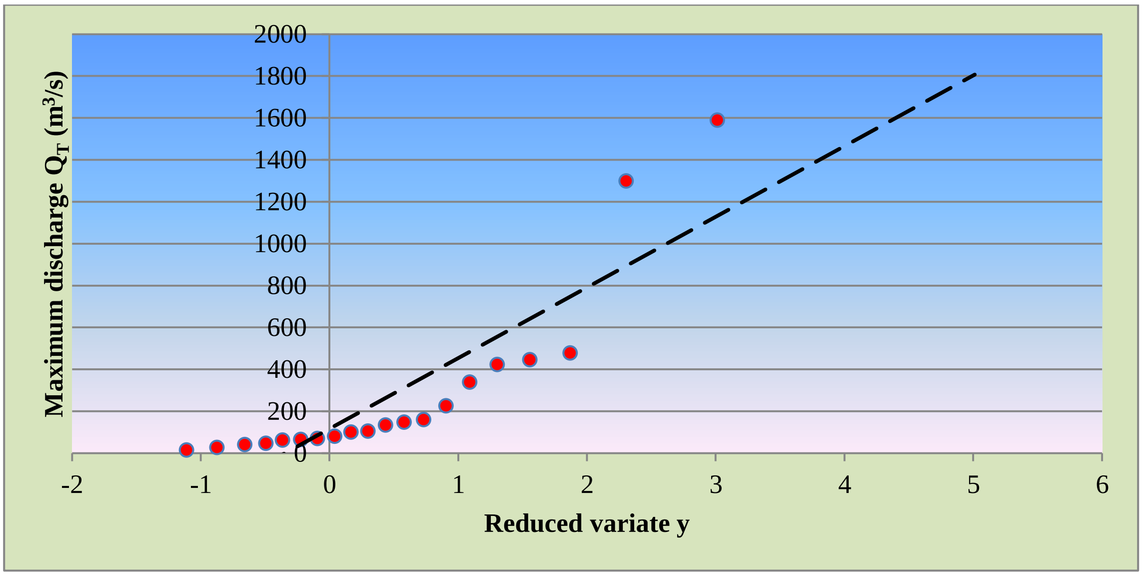

Figure 63: Plot of T-year flood for the Chirua and its reduced variate y

A plot of the reduced variate y and Q for the Chirua at Matambe produced a lesser satisfactory fit as will be seen in Figure 63. This plot produced a relationship defined by:

$$Q_T = 337.27y + 115.77$$

and had a correlation coefficient R^2 of 0.76.

As is evident from Figure 63, the spread of the plots of the reduced variates and the discharges is wide enforcing the observation of the problems met at the station especialy relating to erosion which therefore changes the relationship between gauge height and flow. This difficulty must be related to poor ratings which may not even allow for extrapolation of flows.

<u>Lingadzi at Kaniche, 15.A.8</u>

RGS 15.A.8 was opened in July 1961 (Malawi Government 1986c) with the channel as the control coupled with a solid rock bar at the station. At this point the station's basin area is 450km^2. The station's absolute maximum flow hydrograph is good and continuous from 1974 to 2009 except for the periods 1976 to 1978 and from 2003 to 2006, One exceptionally high flow occurred in 1982 with a discharge of 1,383m^3/s while others were also quite high in excess of 400m^3/s for most of the years (Figure 64) according to available information.

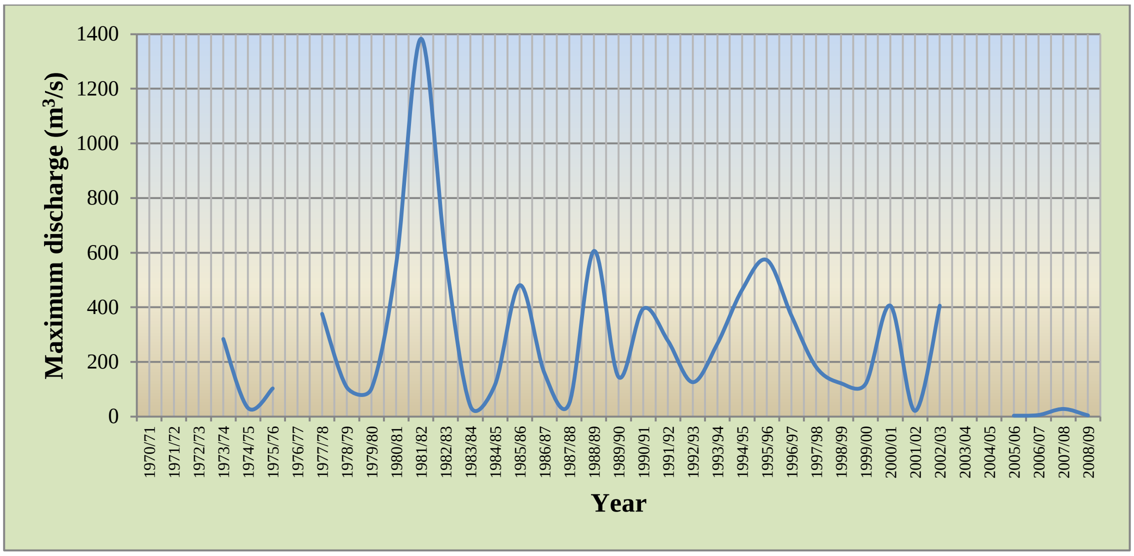

Figure 64: Absolute maximum flows for Lingadzi at Songwe Village (1971-2003)

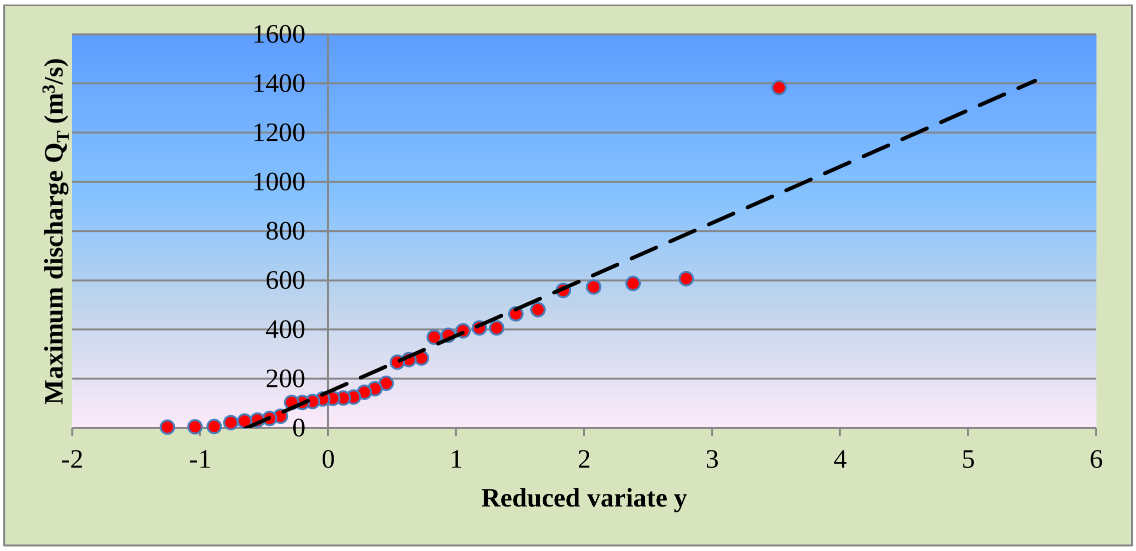

Figure 65: Plot of T-year flood for the Lingadzi and its reduced variate y

A plot of the reduced variate y and Q for the Lingadzi at Songwe Village produced a rather satisfactory fit as will be seen in Figure 65. This plot produced a relationship defined by:

$$Q_T = 229.01y + 145.98$$

and had a correlation coefficient R^2 of 0.88

Figure 65 provides a good spread of plots for this station at lower maximum high flows and shows 2 to 3 outliers at exceptionally high flows within the range of the available records.

<u>Kaombe at Chanika, 15.B.13</u>

This station is located in the fringes of the Forest Reserve of Nkhotakota in a densely vegetated area. It was opened in November 1968 with a natural control but a compound rectangular weir was added later (Malawi Government 1986c). The data is good from 1987 to 2009 with no gaps of missing information (Figure 66). High flows can be in excess of 400 m^3/s in most years indicating the high precipitation that the basin receives especially from the plateau areas above it.

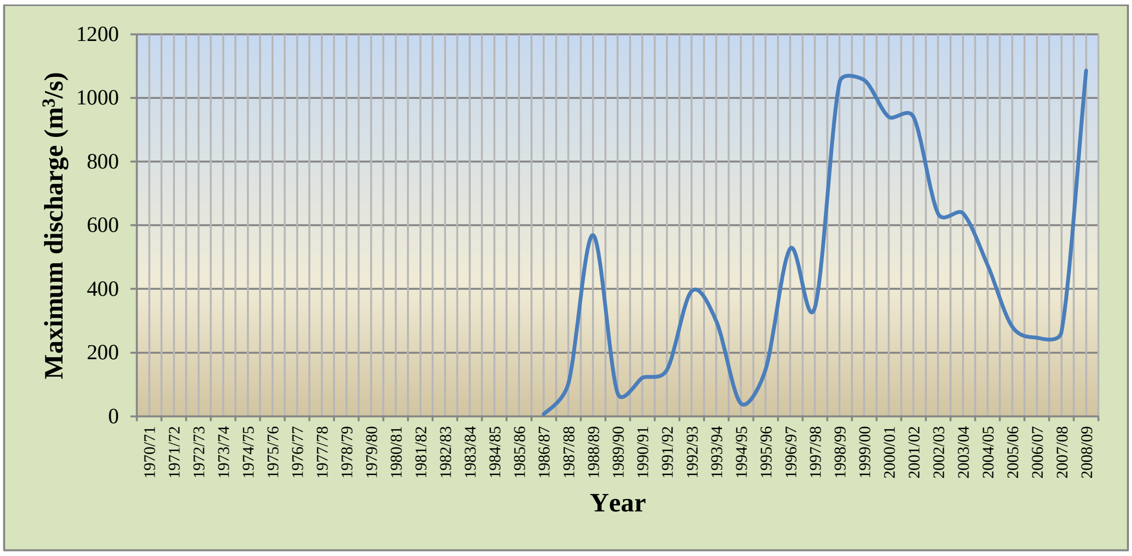

Figure 66: Absolute maximum flows for Kaombe at Chanika (1971-2009)

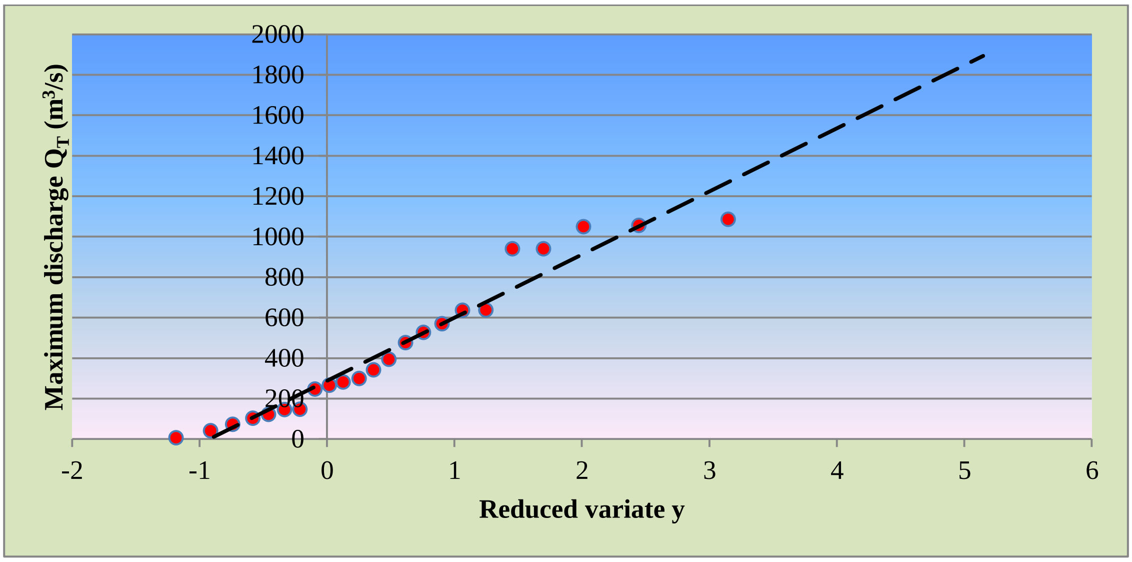

Figure 67: Plot of T-year flood for the Kaombe and its reduced variate y

A plot of the reduced variate y and Q for the Kaombe at Chanika produced a good fit as will be seen in Figure 67. This plot produced a relationship defined by:

$$Q_T = 311.74y + 287.48$$

and had a correlation coefficient R^2 of 0.95

The results of the relationship between the reduced variates and discharges are exceptionally encouraging despite the station having no high-flow measuring facility. This means that the rating for the station is good and can be extrapolated for high flows. Flooding within the basins of the Lakeshore Plain is common and a threat to road infrastructure, people's homes and property as well as their own life. A number of flood incidences have occurred within this super-basin with bridges on the S33 Road washed away. In March 2000 Kaombe River burst its banks and other rivers such as the Likowa, Liudzi and the Lifuliza were in floods. These floods affected many people in the area of T.As Mwadzama and Malengachanzi in Nkhotakota District with 148 families having their houses damaged and 1,764 households losing their crops (Willy and Partners Engineering Services, 2005).

In February 2001 parts of Nkhotakota north were inundated by flood waters with 15, 450 households losing 559 hectares of maize and 748.7 hectares of cassava. Further south in Salima District, the Lingadzi River, the Lipimbi and Chitala were also in floods. About 9,000 households were affected by these floods and 6,048.4 hectares of maize, 962 hectares of rice and 762.6 hectares of cotton were seriously affected. Sadly, 3 people lost their lives. More floods occurred in January and April 2002 and in February 2003 when both Salima and Nkhotakota Districts were affected as a result of high flows within the rivers of Dzongwe, Mauni, Mtamba, Chituku, Kanenge and Kaombe (Willy and Partners Engineering Services, 2005).

Due to the seemingly frequent occurrence of floods in all the river basins of the Central Region, it is necessary that people begin to learn to live with them. This requires that knowledge on the frequency and magnitudes of floods is available in order to avail planners and engineers effectively deal with the impacts of floods on people and the environment. The causes of floods and reasons that exacerbate their magnitudes must be well understood and measures taken to correct where society has gone wrong. This is more to do with promoting SLM, awareness creation among communities on the role unsustainable use of land and its resources plays in triggering floods, the need for capacity building and better land use planning by the ministry responsible for Lands, Housing and Physical Planning.

4.2.2 Flood Data

Data of any kind are important in national development because they provide information from which decisions can be made. The destruction of infrastructure such as bridges and houses and the unwarranted suffering of communities in the rural areas arising from loss of property call for the use of existing data collected throughout the many years gone by in order to develop a tool that can be used in land and country planning as well as in the design of hydraulic structures and avert the full negative impacts with which floods are associated.

The loss of data for a single flood event is regarded as costly because once the flood is gone, its magnitude will not be known. From such a loss, it becomes difficult to estimate flood frequencies with high degree of accuracy because the lost data contributes to that accuracy. The data used in this study are regarded good and can be used with a reasobable degree of confidence. Some of these data have been used by other researchers as they are part of the FRIEND project database (Mkhandi, S. H. and R. K. Kachroo, 1996).

4.3 Development of the Regional Flood Frequency Model

Annual absolute maximum flows from 20 river gauging stations within the Central Region covering the river basins of the South-Western Lakeshore, Linthipe, Bua, Dwangwa and the Nkhotakota Lakeshore were collected from the Ministry responsible for water affairs in Malawi. The data collected for each station was from about 1971 because the researcher wanted to ensure that the floods were within the same "generation". If for instance the data collected for some stations ranged from the 1950s to 1980s and for other stations the data were from the 1970s to 2000s, there would expectedly be discrepancies as there are cycles in climatic events which would distort the analysis.

These annual instentaneous maximum flows were isolated for each RGS and ranked from the highest to the smallest as seen in Appendices B to U. The ranked series were aligned against their rank from 1 to 20 to calculate the return period of the occurrence of each flood magnitude. The return period was obtained by using the following formula:

$$\mathbf{T = (n + 1)/m}$$

Where T is the return period in years;
n is the number of the ranked series; and
m is the rank.

The probability of occurrence of a given flood of magnitude Q and being exceeded was calculated using the formula:

$$P = 1/(n+1)$$

Where P is the probability of a flood of magnitude Q occurring and being exceeded; and

n is the number of the series.

In engineering projects which involve floods where the aim would be to reduce the probability of a particular flood from destroying infrastructure and property, it is desired that such engineering project suffer the least in many years. To this extent the probability of a flood of magnitude Q being equalled or exceeded would be of little value for design purposes and therefore that probability should be which provides for non-excedence. Since the probability of exceedence is known, therefore that of non-excedence is given by:

$$P' = 1 - 1/(n+1)$$

Where P' is the probability of a flood of magnitude Q not being equalled or exceeded; and

n is the number of the series.

The given flood magnitudes from the 20 RGSs were plotted against their reduced variates given by the formula:

$$y = -\ln\left[-\ln\left(1 - 1/T\right)\right]$$

The plotted variables gave the following relationship:

$$Q_T = ay + b$$

Where Q_T is a flood of magnitude Q occurring and not being equalled or exceeded;

a is a coefficient;

y is the reduced variate; and

b is constant.

This relationship was used to generate a flood frequency formula for each of the RGSs within the region which took the form:

$$Q_T \quad = \quad a \,.\, \ln(T) \pm b$$

The regression analysis for all the 20 stations with the exception of Lilongwe River (4.D.6), Lingadzi River (4.E.2) and Chirua River (15.A.4) gave correlation coefficients R^2 of between 0.918 to 0.985 while the three stations gave correlation coefficients R^2 of 0.857 for Lilongwe, 0.860 for Chirua and 0.892 for Lingadzi. The flood frequency formulae for the 20 stations are given in Table 17 below.

Table 17: River basins of the Central Region and their flood frequency formulae

RIVER AND R.G.S NUMBER	EQUATION	R^2
Namikokwe 3.E.2	$Q_{(T)} = 27.632 \ln(T) + 6.432$	0.980
Livulezi 3.E.3	$Q_{(T)} = 47.765 (T) – 60.361$	0.952
Namikokwe 3.E.5	$Q_{(T)} = 54.298 \ln(T) – 9.529$	0.962
Linthipe 4.B.1	$Q_{(T)} = 1015.7 \ln(T) – 41.555$	0.935
Linthipe 4.B.3	$Q_{(T)} = 173.95 \ln(T) + 50.07$	0.958
Linthipe 4.B.9	$Q_{(T)} = 624.41 \ln(T) + 90.278$	0.955
Lilongwe 4.C.2	$Q_{(T)} = 279.04 \ln(T) + 123.7$	0.941
Lilongwe 4.D.4	$Q_{(T)} = 107.77 \ln(T) + 12.425$	0.985
Lilongwe 4.D.6	$Q_{(T)} = 99.669 \ln(T) + 34.630$	0.857
Lingadzi 4.E.1	$Q_{(T)} = 160.73 \ln(T) + 55.054$	0.932
Lingadzi 4.E.2	$Q_{(T)} = 44.278 \ln(T) + 8.868$	0.892
Lumbadzi 4.F.6	$Q_{(T)} = 508.31 \ln(T) – 76.792$	0.963
Bua 5.C.1	$Q_{(T)} = 406.38 \ln(T) + 157.89$	0.981
Mtiti 5.D.3	$Q_{(T)} = 16.790 \ln(T) + 0.683$	0.945
Rusa 5.F.1	$Q_{(T)} = 65.198 \ln(T) – 15.376$	0.952
Dwangwa 6.C.1	$Q_{(T)} = 60.600 \ln(T) + 39.677$	0.938
Mpasadzi 6.C.5	$Q_{(T)} = 49.206 \ln(T) + 0.8394$	0.981
Chirua 15.A.4	$Q_{(T)} = 481.57 \ln(T) – 154.47$	0.860
Lingadzi 15.A.8	$Q_{(T)} = 310.87 \ln(T) – 25.339$	0.918
Kaombe 15.B.13	$Q_{(T)} = 412.38 \ln(T) + 66.305$	0.926

The equations in Table 17 were each used in calculating the flood magnitudes for the 10, 20, 50 and 100-year return period for the individual stations which would later provide a pointer towards calculating a flood of magnitude Q for any given return period of choice. These quantities appear in Table 18.

Table 18: Flood flows at return periods of 10, 20, 50 and 100 years for the 20 stations

RIVER	Area (km^2)	Q(10)	Q(20)	Q(50)	Q(100)
Namikokwe 3.E.2	129	70.0	89.2	114	134
Livulezi 3.E.3	452	49.6	82.7	126	160
Namikokwe 3.E.5	44	115	153	203	240
Linthipe 4.B.1	8,070	2,297	3,001	3,932	4,636
Linthipe 4.B.3	600	451	571	730	851
Linthipe 4.B.9	2,930	1,528	1,961	2,533	2,966
Lilongwe 4.C.2	4,940	766	960	1,215	1,409
Lilongwe 4.D.4	1,870	261	335	434	509
Lilongwe 4.D.6	763	264	333	424	494
Lingadzi 4.E.1	928	425	536	684	795
Lingadzi 4.E.2	585	111	141	182	213
Lumbadzi 4.F.6	424	1,094	1,446	1,912	2,264
Bua 5.C.1	10,600	1,094	1,375	1,748	2,029
Mtiti 5.D.3	233	39.3	51.0	66.4	78.0
Rusa 5.F.1	2,580	135	180	240	285
Dwangwa 6.C.1	2,980	179	221	277	319
Mpasadzi 6.C.5	309	114	148	193	227
Chirua 15.A.4	228	954	1,288	1,729	2,063
Lingadzi 15.A.8	450	690	906	1,191	1,406
Kaombe 15.B.13	300	1,016	1,302	1,680	1,965

4.3.1 Estimating the T-Year Flood

Since the 20 stations each had an applicable equation with which it was now possible to calculate the T-year flood, the process was repeated using these formulae to calculate the 5, 10, 20, 25, 50 and 100-year flood magnitudes in m^3/s. The quantities of this process appear in Table 19 below.

Table 19: Expected flood flows at given return periods for the 20 stations

Name of River	Return Period (Years)					
	5	10	20	25	50	100
Namikokwe 3.E.2	50.9	70.0	89.2	95.4	114	134
Livulezi 3.E.3	178	417	955	1134	2328	4716
Namikokwe 3.E.5	77.9	115	153	168	203	240
Linthipe 4.B.1	1593	2297	3001	3228	3932	4636
Linthipe 4.B.3	330	451	571	610	730	851
Linthipe 4.B.9	1095	1528	1961	2100	2533	2965
Lilongwe 4.C.2	573	766	960	1022	1215	1409
Lilongwe 4.D.4	186	261	335	359	434	509
Lilongwe 4.D.6	195	264	333	355	424	494
Lingadzi 4.E.1	314	425	536	572	684	795
Lingadzi 4.E.2	80.1	111	141	151	182	213
Lumbadzi 4.F.6	741	1094	1446	1559	1912	2264
Bua 5.C.1	812	1094	1375	1466	1748	2029
Mtiti 5.D.3	27.7	39.3	50.9	54.7	66.4	78.0
Rusa 5.F.1	89.6	135	180	204	240	285
Dwangwa 6.C.1	137	179	221	235	277	319
Mpasadzi 6.C.5	80.0	114	148	159	193	227
Chirua 15.A.4	620	954	1288	1396	1729	2063
Lingadzi 15.A.8	475	690	906	975	1192	1406
Kaombe 15.B.13	730	1016	1302	1394	1679	1965

Having calculated the T-year flood magnitudes for the 20 stations it was observed that there were some small basins having unexpectedly high flows at given return periods such as Livulezi, Lumbadzi, Chirua, Lingadzi and Kaombe. Similarly, there were also some large river basins that were reflecting unexpectedly low flows at given return periods such as Lilongwe 4.D.4, Lilongwe 4.D.6, Rusa 5.F.1 and Dwangwa 6.C.1. In the case of the lakeshore rivers, where the channel shape and gradient change, it is not possible to completely measure the whole flow as some of it is left to flow over the river's banks.

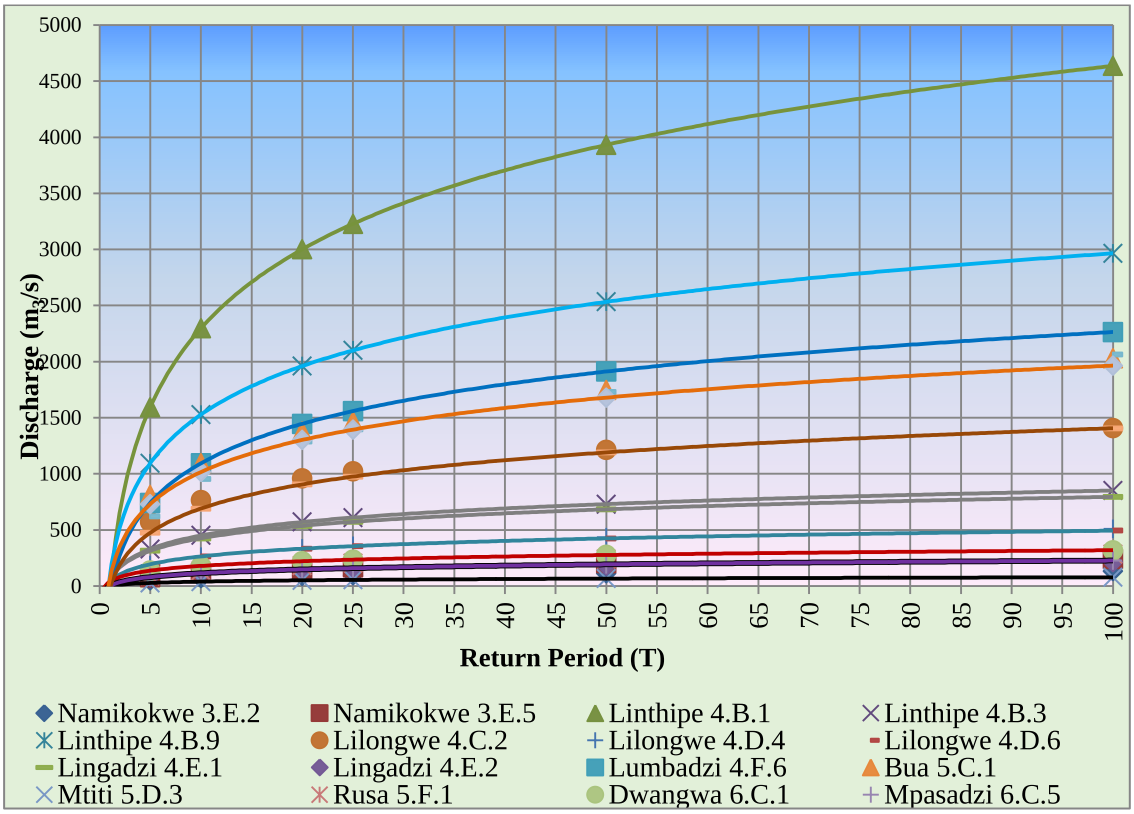

Figure 68: A plot of floods of magnitude Q and their return periods

This reasoning is strengthened by observations made elsewhere in Ethiopia. Again, because of the nature of the soils in this area, scouring of the river bed and/or the river banks can also effectively change the gradient of the rating between stage and discharge just as high siltation of the river bed can also have the same effect. Tadesse and his colleagues (2005) observed that the river gauging station for the Awash River which is located downstream of the flood plain has flows flowing in and over the flood plain rather than being wholly confined to the river channel.

In this regard, the peak flows are exceedingly smoothened rendering it difficult to register them as high flows. They acknowledge the fact that this smothering of flood flows "…did not at all correspond to the drainage sizes as compared to the other stations situated in similar climatic, physico-geographical condition and receiving more or less the same magnitude of rainfall" (page 12) The observations made with some of the river gauging stations in the Central Region which has a large and wide lakeshore plain are therefore not surprising. The expected flood magnitudes appearing in Table 19 were plotted against their respective return periods for all the stations as seen in Figure 68.

The visual presentation of the relationship between floods and their return periods in

Figure 68 indicates that river basins with small catchment areas lie at the bottom and those with large areas take the top positions. Nonetheless there are others such as the Dwangwa which are at the bottom and yet they have relatively a large basin area.

Flood frequency analysis cannot be complete without recognising the importance of homogeneity of the river basins being considered. River basins ought to have similar climatic, topographical, geological, lithological and other features but this does not mean that these features are necessarily the same for they cannot be. In order to develop a regional frequency model for the Central Region therefore, the river gauging stations were subjected to a homogeneity test. Several homogeneity methods are available and have been used by researchers such as by Opere et al (2005), Mishra, et al (2008) and Gorbachova, et al (2013) among the many others. The major objective of a homogeneity test is to achieve a more reliable result arising from the statistics.

4.3.2 Regional Homogeneity Test

The method used for testing homogeneity of the river gauging stations of the Central Region used in this study is the discordancy measure, also known as the STU-index method which considers the means of the en situ data, including and excluding the largest instentaneous maximum flow values obtained from those stations. The mean annual absolute maximum flow $\bar{Q}_{1g}$ at a particular gauging station g including the largest value in the series is given by:

$$\bar{Q}_{1\boldsymbol{g}} = \frac{1}{n} \sum_{i=1}^{n}$$

Where $\bar{Q}_1$ is the mean absolute maximum flow including the highest value;

n is the total number of the series;

g is the river gauging station; and

i is the series.

Similary, the mean annual absolute maximum flow $\bar{Q}_{2g}$ at a particular gauging station g excluding the largest value in the series is given by:

$$\bar{Q}_{2g} = \frac{1}{n-1} \sum_{i=1}^{n-1} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Upon computing the two values $\bar{Q}_{1g}$ and $\bar{Q}_{2g}$ it is possible to calculate the discordancy measure which in this case is represented by the symbol ɖ. The discordancy measure is then computed using the formula:

$$\text{ɖ} = \frac{\bar{Q}_{1g} - \bar{Q}_{2g}}{\text{ƴ}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Where	ɖ	is the discordancy measure or the STU index;
	$\bar{Q}_{1g}$ and $\bar{Q}_{2g}$	are as explained above; and
	ƴ	is as given in the equation below.

$$\text{ƴ} = \left(\frac{(\bar{Q}_{1g})^2}{n} + \frac{(\bar{Q}_{2g})^2}{n-1} \right)^{½} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

The computed values of ɖ from equation (2) are then ranked from smallest to largest valued and these are arrayed against their rank. When plotted, if the resultant plot shows a straight line, then the region in which the river gauging stations are located is considered homogeneous. This process was performed for all the stations used in this study as illustrated by Table 20.

Table 20: Calculated values for generating STU indices

No.	3E2	3E3	3E5	4B1	4B3	4B9	4C2	4D4	4D6	4E1	4E2	4F6	5C1	5D3	5F1	6C1	6C5	15A4	15A8	15B13
1.	4.10	2.55	2.01	152	45.8	86.4	87.6	8.40	7.35	11.8	4.66	17.4	129	0.30	0.90	16.5	4.47	14.0	3.35	6.71
2.	4.82	4.60	3.41	174	50.3	86.4	110	10.7	25.2	46.0	4.73	35.0	176	0.34	1.53	19.0	6.48	26.7	4.32	40.2
3.	5.99	4.84	4.01	180	51.0	102	122	14.9	33.9	60.4	5.34	38.6	195	0.52	1.81	22.8	7.89	39.8	5.73	72.4
4.	6.90	4.97	4.11	210	66.0	115	133	14.9	37.2	63.5	13.2	49.6	196	0.59	2.34	23.3	8.2	46.5	21.0	103
5.	9.11	5.05	5.20	246	82.4	200	135	18.9	45.9	68.4	15.5	60.0	201	0.60	4.82	27.1	14.8	61.4	27.9	121
6.	11.6	5.10	5.33	260	82.4	210	158	21.5	53.1	86.6	19.9	67.6	216	1.05	6.22	34.2	15.2	64.1	31.4	146
7.	11.6	5.49	5.95	268	83.6	234	171	21.9	60.2	86.6	25.0	67.6	240	1.10	7.02	43.7	16.3	68.9	38.9	147
8.	13.6	5.65	7.61	277	94.4	243	189	27.9	77.0	91.5	33.0	123	240	1.99	7.02	51.3	18.2	80.2	47.4	247
9.	14.2	5.69	8.25	300	108	283	264	35.4	109	96.6	33.6	135	244	2.23	8.01	61.5	23.0	99.4	103	265
10.	16.1	5.80	11.5	347	120	283	274	51.9	126	97.6	35.9	166	246	3.59	9.51	62.2	23.3	105	103	282
11.	20.9	6.79	11.9	400	122	312	291	60.6	170	98.7	36.3	198	248	4.20	9.58	70.2	23.5	134	107	299
12.	25.1	8.55	13.0	412	123	340	294	64.5	179	163	37.9	217	257	9.40	10.7	71.5	32.4	148	117	342
13.	25.6	32.9	17.3	420	136	427	304	69.3	188	164	39.6	234	258	10.4	11.9	74.6	33.8	159	120	393
14.	27.2	38.6	30.6	584	151	427	351	70.2	214	178	39.6	527	314	11.8	13.5	75.7	34.5	226	122	476
15.	30.5	45.5	35.3	590	156	456	357	83.4	214	185	41.7	547	374	15.5	13.5	81.7	35.0	339	126	527
16.	31.5	45.5	48.5	591	162	462	380	91.1	231	216	44.2	605	444	15.8	14.6	81.9	35.1	422	145	569
17.	32.2	46.8	49.0	601	173	490	384	93.1	250	237	46.6	684	463	17.0	15.2	82.8	38.5	446	159	636
18.	32.6	53.6	49.0	615	177	530	395	98.2	256	237	47.4	952	472	18.4	21.7	83.9	49.6	478	181	638
19.	32.9	63.1	58.3	623	207	551	401	107		275	49.1	1056	528	19.6	24.8	92.6	60.8		267	940
20.	32.9	68.9	58.8	658	239	596	454	119		279	50.3	1185	535	19.6	40.8	93.0	68.1		277	940
21.	33.3	73.2	79.2	668	258	645	480	124		320	53.6	1350	535	19.8	46.8	97.8	83.4		284	1049
22.	37.3	82.2	105	668	259	647	484	124		360	54.1		539	22.8	50.1	106	91.9		369	1056
23.	38.1	84.1	126	681	261	647	503	124		384	54.6		556	24.1	56.0	116	98.3		376	1086
24.	47.7	112	147	682	286	659	509	146		409	54.6		622	29.1	62.7	116	105		395	

25.	57.4	112	149	730	288	694	630	156		434	54.6		626	31.1	101	118	143		406	
26.	59.3	169		945	296	738	834	172		442	59.6		642	31.3	110	118	153		406	
27.	63.2	184		1058	296	741	845	174		480	121		702	32.4	119	139			464	
28.	70.2	234		1259	300	1170	865	181			142		706	32.4	144	141			481	
29.	83.7	261		1433	300	1266	947	205			152		727	34.9	154	144			559	
30.	96.9	314		1658	326	1439		214			152		739	50.4	173	145			573	
31.		384		1713	539	1439		219					752	51.2	193	145			587	
32.		433		1713	558	1757		250					893			156			606	
33.				1797	701	1826		335					903			172			1383	
34.				3306		1837		398					1042			174				
35.				3403		1992							1093			216				
36.				3691									1402			232				
37.													1703							
Q_{1g}	**32.6**	**90.7**	**41.4**	**925**	**215**	**684**	**391**	**115**	**126**	**206**	**50.7**	**396**	**545**	**16.6**	**46.3**	**97.4**	**47.1**	**164**	**269**	**451**
Q_{2g}	***30.4***	***80.0***	***37.1***	***848***	***200***	***646***	***372***	***106***	***119***	***196***	***47.3***	***350***	***514***	***15.4***	***41.6***	***93.6***	***43.0***	***146***	***236***	***424***
STU	**0.26**	**0.50**	**0.38**	**0.37**	**0.29**	**0.24**	**0.19**	**0.33**	**0.17**	**0.18**	**0.27**	**0.39**	**0.25**	**0.29**	**0.42**	**0.17**	**0.32**	**0.34**	**0.53**	**0.21**

The results from Table 20 were plotted as seen in Figure 69 where it was observed that they produced a good straight line.

Figure 69: Plot of STU-Indices and their rank for the 20 stations of the Central Region

The relationship of the variables is given by the equation:

$$d = 0.0172z + 0.1242$$

Where d is the discordancy measure; and

z is the rank.

This relationship gave a correlation coefficient R^2 of 0.956 and was therefore good enough to believe that the region is homogeneous.

4.3.3 Regionalising the T-Year Flood

The equations given in Table 17 for each of the stations are relevant in computing flows at their given return periods but do not provide for estimating T-year floods for ungauged catchments or any part of that river channel below or above the gauging station. However, they are a first step towards developing a regional flood frequency model for the Central Region. The normal procedure in regional flood frequency analysis is to make the quantities dimensionless where the computed T-year values are divided by their mean i.e. $Q/\bar{Q}$.

For ungauged catchments, the value of $\bar{Q}$ cannot be readily available and this would pose as a challenge to the design engineer. To deal with this challenge, the values of $\bar{Q}$ were computed from the data and the annual absolute maximum discharges for each station were divided by the mean to get the desired dimensionless values. Since this work is intended to be used for the design of upcountry engineering works where it may not be possible to find flow data on some rivers and streams, it was considered prudent to link the Q/Q̄ values with the basin area. Considering that it would be possible to calculate the flow at a given return period as given in Table 17, the inclusion of the basin area would facilitate the computation of flows for any ungauged catchment.

However, it is important that a good relationship ought to be developed between the dimensionless values of Q/Q̄ and the basin area. The results of the computation are given in Table 21 but when Q/Q̄ values are plotted against their respective basin areas, the relationship was weak with a correlation coefficient R^2 of marginally above 0.6

Table 21: Values of Q̄ and Q_T/Q̄ for the 20 stations of the Central Region

RIVER	Q̄	Q(10)/Q̄	Q(20)/Q̄	Q(50)/Q̄	Q(100)/Q̄
Namikokwe 3.E.2	32.6	2.15	2.74	3.50	4.11
Livulezi 3.E.3	90.7	0.55	0.91	1.38	1.76
Namikokwe 3.E.5	41.4	2.78	3.70	4.90	5.80
Linthipe 4.B.1	925	2.48	3.24	4.25	5.01
Linthipe 4.B.3	215	2.10	2.66	3.40	3.96
Linthipe 4.B.9	684	2.23	2.87	3.70	4.34
Lilongwe 4.C.2	391	1.96	2.46	3.11	3.60
Lilongwe 4.D.4	115	2.27	2.91	3.77	4.43
Lilongwe 4.D.6	126	2.09	2.64	3.36	3.92
Lingadzi 4.E.1	206	2.06	2.60	3.32	3.86
Lingadzi 4.E.2	50.7	2.19	2.78	3.59	4.20
Lumbadzi 4.F.6	396	2.76	3.65	4.83	5.72
Bua 5.C.1	545	2.01	2.52	3.21	3.72
Mtiti 5.D.3	16.6	2.37	3.07	4.00	4.70
Rusa 5.F.1	46.3	2.92	3.89	5.18	6.16
Dwangwa 6.C.1	97.4	1.84	2.27	2.84	3.28
Mpasadzi 6.C.5	47.1	2.42	3.14	4.10	4.82
Chirua 15.A.4	164	5.82	7.85	10.5	12.6
Lingadzi 15.A.8	269	2.56	3.37	4.43	5.23
Kaombe 15.B.13	451	2.25	2.89	3.72	4.36

An attempt was then made to link the observed mean values of the annual absolute maximum flows $\bar{Q}$ to the basin area. The assumption in using this approach is that being a homogeneous region, the mean values can also be ranked with their basin areas from the largest to the smallest. Linsley, et al. (1975) state that a relationship is required to define the mean annual flood and often this is a simple relationship between $\bar{Q}$ and the drainage area. The mean values obtained from the data for each station were then plotted against their basin areas as seen in Figure 70.

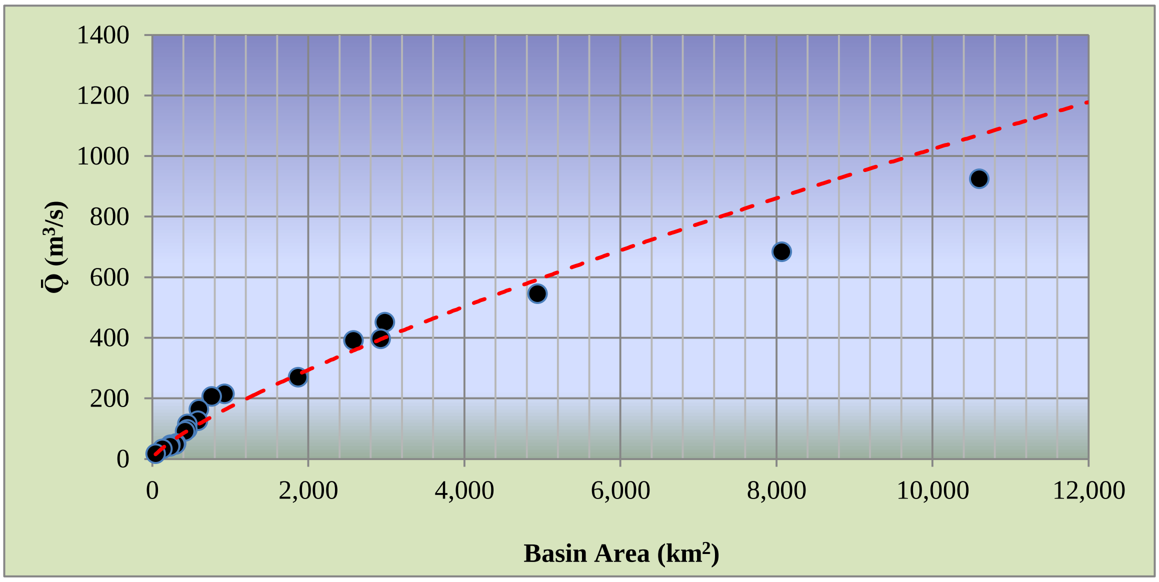

Figure 70: Plot of basin area (km^2) against mean of absolute maxima ($\bar{Q}$).

The derived relationship was of the form:

$$\bar{Q} = 0.814A^{0.77}$$

Where	$\bar{Q}$	is the mean of the annual absolute maxima (m^3/s);
and	A	is the basin area (km^2)

This relationship gave a correlation coefficient of R^2 of 0.96 with a power value of 0.77. The same process was repeated for values of Q_5, Q_{10}, Q_{20}, Q_{25}, Q_{50} and Q_{100} as calculated from the given equations of Table 17. These values are displayed against their basin areas, ranked from highest to lowest in Table 22.

Table 22: Calculated T-year flood flows against basin areas ranked highest to smallest

Area (km^2)	Q_5	Q_{10}	Q_{20}	Q_{25}	Q_{50}	Q_{100}
10,600	1593	2297	3001	3228	3932	4636
8,070	1095	1528	1961	2100	2533	2965
4,940	812	1094	1446	1559	1912	2264
2,980	741	1094	1375	1466	1748	2029
2,930	730	1016	1302	1394	1679	1965
2,580	620	954	1,288	1396	1729	2063
1,870	573	766	960	1022	1215	1409
928	475	690	955	1134	2328	4716
763	330	451	906	975	1192	1406
600	314	425	571	610	730	851
585	195	417	536	572	684	795
452	186	264	335	359	434	509
450	178	261	333	355	424	494
424	137	179	221	235	277	319
309	89.6	135	180	204	240	285
300	80.1	115	153	168	203	240
233	80	114	148	159	193	227
228	77.9	111	141	151	182	213
129	50.9	70	89.2	95.4	114	134
44	27.7	39.3	50.9	54.7	66.4	78

The plots of this relationship are presented in Figures 71 – 76. The following relationships were obtained:

Q_5	$1.41A^{0.77}$;	$R^2 = 0.95$;
Q_{10}	$2.08A^{0.77}$;	$R^2 = 0.94$;
Q_{20}	$2.74A^{0.77}$;	$R^2 = 0.93$;
Q_{25}	$2.94A^{0.77}$;	$R^2 = 0.93$;
Q_{50}	$3.17A^{0.77}$;	$R^2 = 0.93$; and
Q_{100}	$3.08A^{0.82}$;	$R^2 = 0.94$

As may be observed a power factor of 0.77 is common in all relationships (except of course for Q_{100}) which is also the same as that which was obtained for the plot between $\bar{Q}$

and the drainage area. In order to generate the appropriate coefficient C which could be used in a relationship of the form appearing below (Figures 71 – 76), the Q_5 – Q_{100} coefficients were again plotted against their return periods and this is seen in Figure 77.

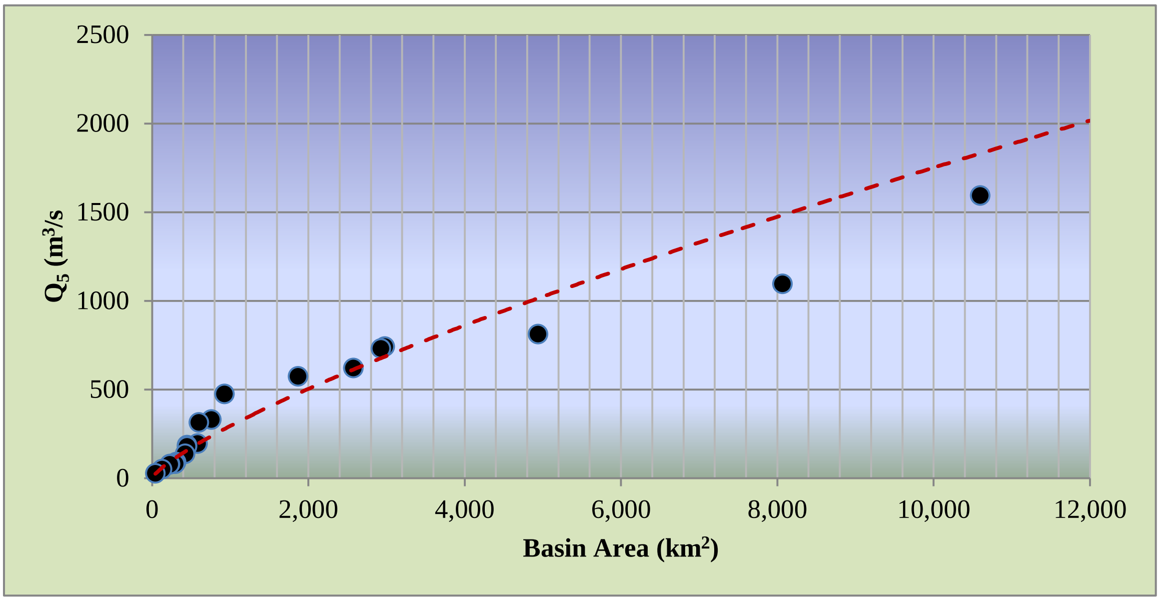

Figure 71: Plot of Q_5 and Basin Area

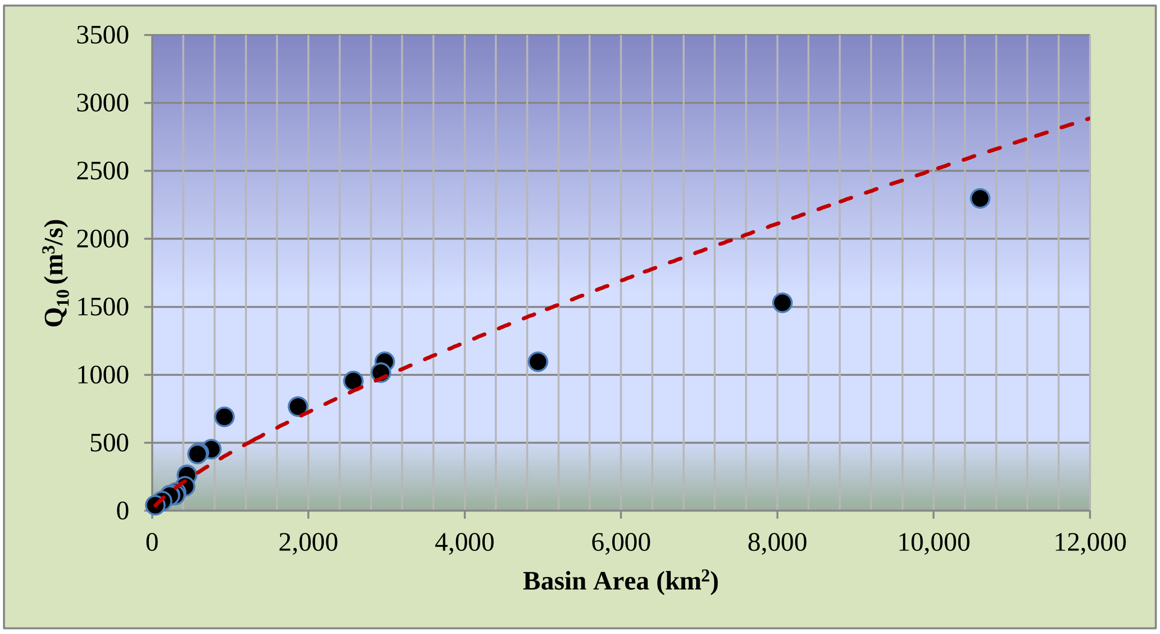

Figure 72: Plot of Q_{10} and Basin Area

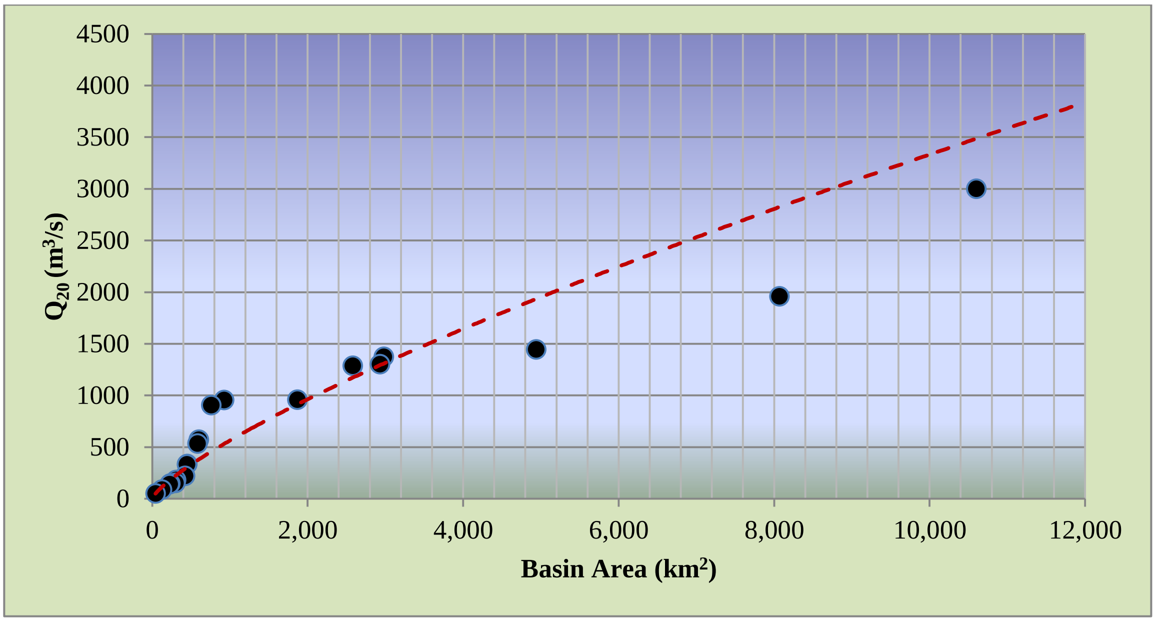

Figure 73: Plot of Q_{20} and Basin Area

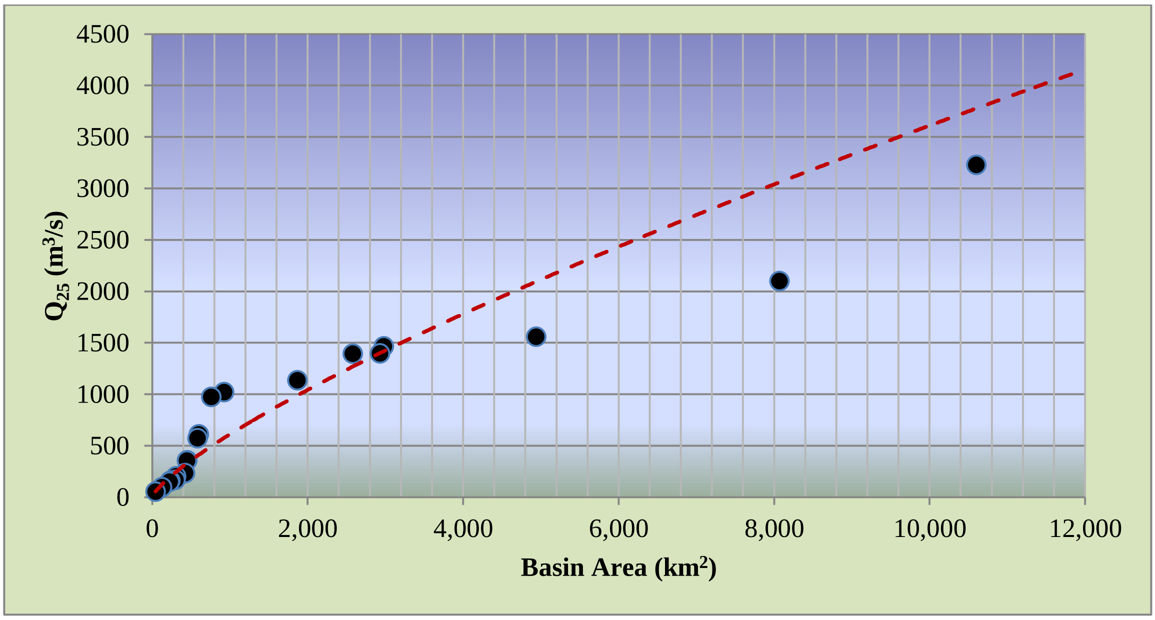

Figure 74: Plot of Q_{25} and Basin Area

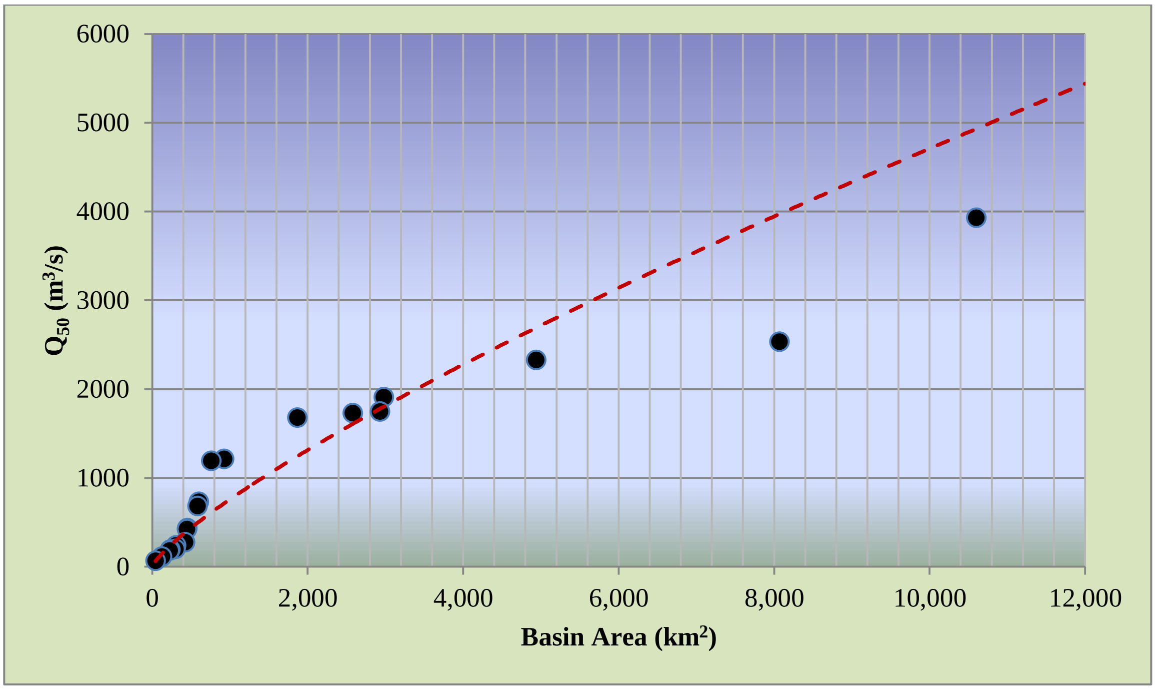

Figure 75: Plot of Q_{50} and Basin Area

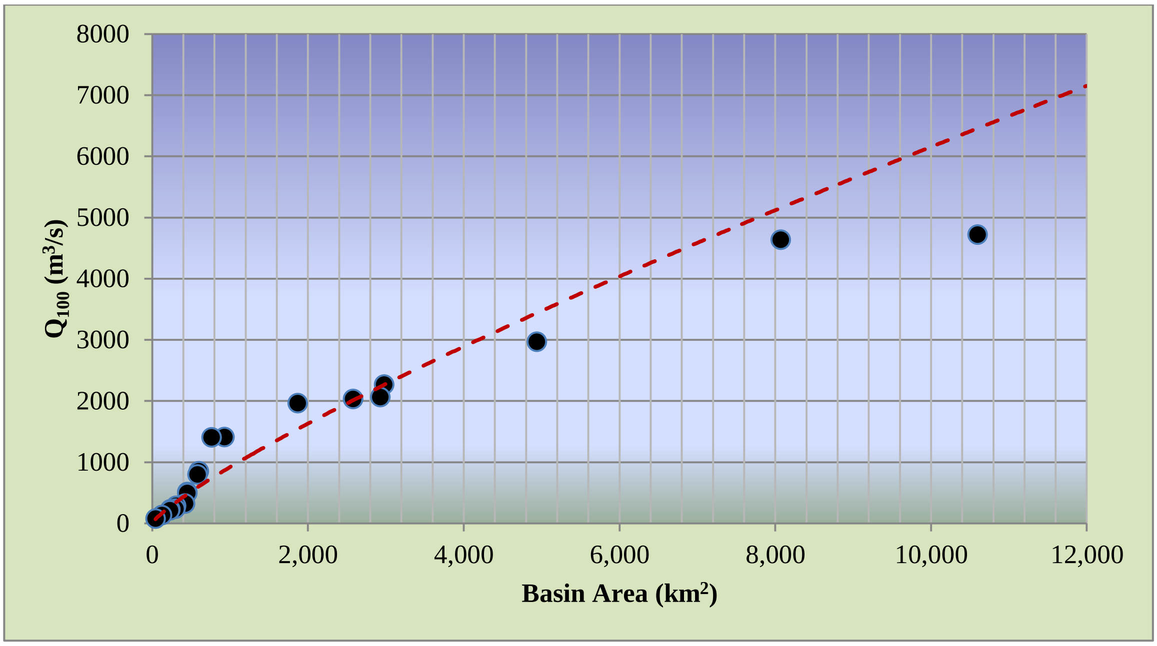

Figure 76: Plot of Q_{100} and Basin Area

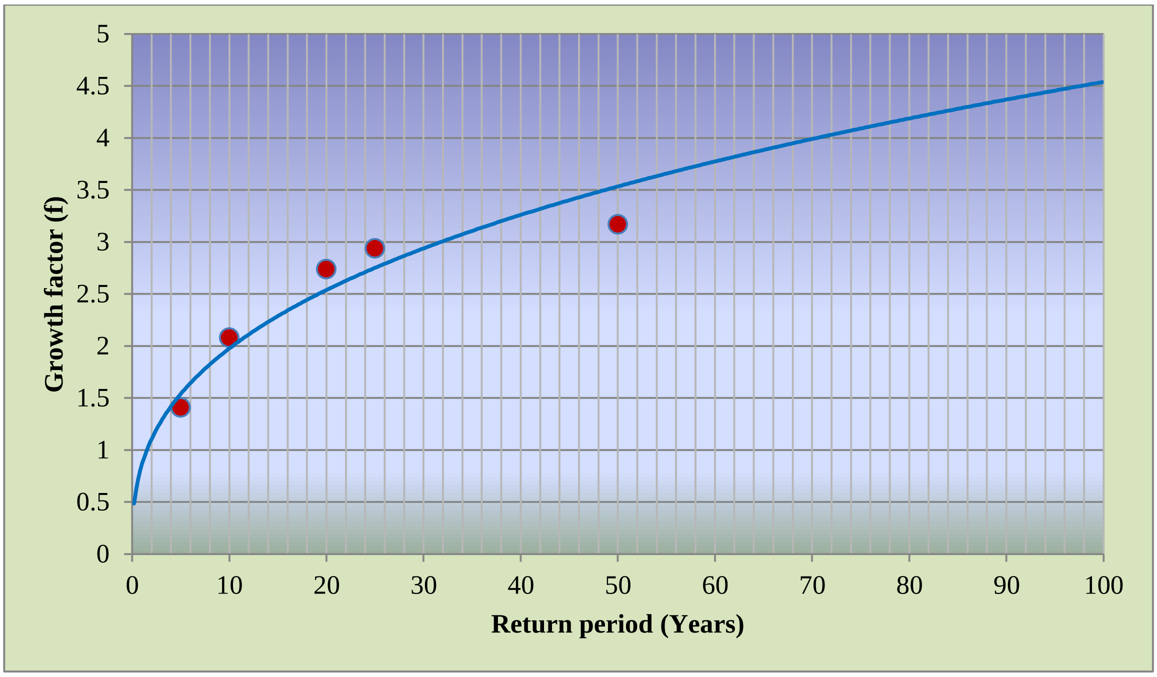

Figure 77: Generating the Growth Factor (f)

Figure 77 provides the growth factor ***f*** for calculating maximum flood flows for any ungauged catchment combined with its basin area. The growth factor ***f*** is of the form:

$$\boldsymbol{f} \quad = \quad \mathbf{0.86\ (T_r)^{0.36}}$$

Where f is the growth factor; and

Tr is the return period substituting for Q_5…...Q_T

The proposed flood frequency model for the Central Region of Malawi is now therefore:

$$\mathbf{Q_{(Tr)} \quad = \quad 0.86\ (T_r)^{0.36}\ .\ A^{0.77}}$$

Where Q is the desired maximum flow in m^3/s; and

Tr is the chosen return period.

This relationship has a correlation coefficient of 0.93 and can be used for any river basin within the Central Region of Malawi in calculating the flood magnitude Q for any return period T (years).

4.4 Testing the Flood Frequency Models

Using the existing methods by Pike (1971), Krishnamurthy (1987), data from individual stations, the Gumbel method and the proposed method, estimates of flood flows were computed for five river gauging stations with different basin areas – from the smallest to the largest. The rivers used were:

Namikokwe	(129km^2);
Lingadzi	(450km^2);
Lilongwe	(1,870km^2);
Dwangwa	(2,980km^2); and
Bua	(10,600km^2).

The computed values are presented in Tables 23 – 27 and were plotted against their return periods as seen in Figures 78 – 82.

Table 23: Computed flood flows for Namikokwe River using the available methods

NAMIKOKWE 3.E.2 (129 km^2)						
Proposer	**Return Period (Years)**					
	5	**10**	**20**	**25**	**50**	**100**
Gumbel	52.5	68	82.9	87.6	102	117
Pike (1971)	-	-	-	836	965	1126
Krishnamurthy (1987)	-	39.8	93.6	-	115	130
Proposed model (2014)	64.7	83.1	107	115	148	190
Data	50.9	70	89.2	95.4	114	134

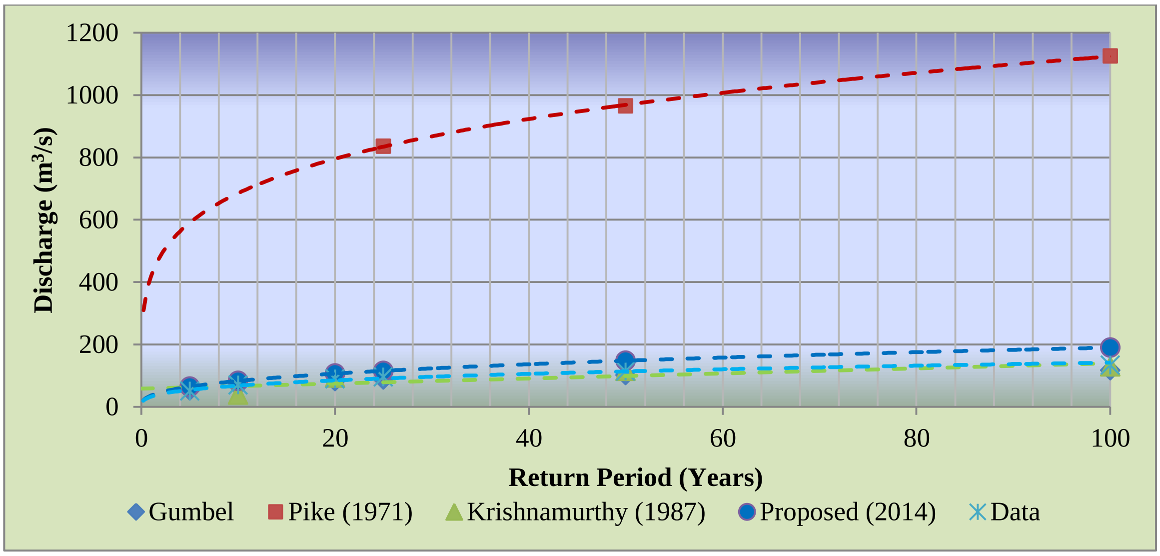

Figure 78: Graphical presentation of flood flows of Namikokwe River

From Figure 78 the entire flood estimates show closeness except for those figures obtained by the use of Pike's method.

Table 24: Computed flood flows for Lingadzi River using available methods

LINGADZI 15.A.8 (450 km^2)						
Proposer	**Return Period (Years)**					
	5	**10**	**20**	**25**	**50**	**100**
Gumbel	489	661	826	878	1040	1200
Pike (1971)	-	-	-	577	721	901
Krishnamurthy (1987)	-	146	177	-	217	246
Proposed model (2014)	169	218	279	302	388	498
Data	475	690	906	975	1192	1406

With respect to the Lingadzi River (Table 24 and Figure 79) located on the Lakeshore, the estimates obtained from the proposed method and those from Krishnamurthy's method are lower than 600m^3/s even for a return period of 100 years. Results obtained from the gauging station show the highest flood estimates of 1,406m^3/s for the 100-year flood but for a basin of the size of only 450km^2 this figure would intuitively be an overestimate.

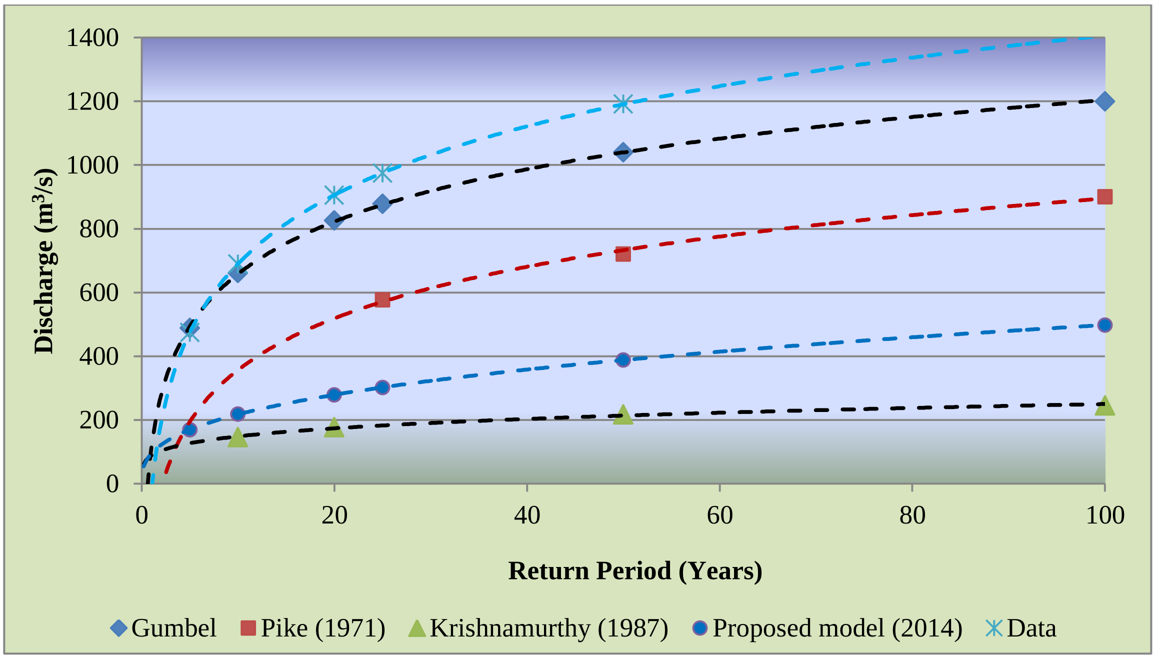

Figure 79: Graphical presentation of flood flows of Lingadzi River

In addition, there has never been and there is no automatic water level recorder at this station which would otherwise have given real values of the absolute maximum water levels for use in the preparation of the rating curve (Water Department, 2014a). Equally true there has also never been a cable car for use in the measurement of high discharges. The records for the high flows could therefore be said to be exaggerated.

Information on the estimated flood flows for the Lilongwe River using the available methods and the proposed model appears in Table 25 and Figure 80. While all other methods show estimates lower than those given by the proposed method, it is considered that the new method provides a true picture of the floods of this basin because of two reasons. First, during all times, the Lilongwe Water Board (LWB) draws huge amounts from its Area 3 intake for water supply to the City of Lilongwe which is never taken into account at RGS 4.D.4 (Lilongwe at Old Town) station downstream.

Table 25: Computed flood flows for Lilongwe River using available methods

LILONGWE 4.D.4 (1,870 km^2)						
Proposer	**Return Period (Years)**					
	5	**10**	**20**	**25**	**50**	**100**
Gumbel	192	253	311	330	387	443
Pike (1971)	-	-	-	612	735	857
Krishnamurthy (1987)	-	302	366	-	448	509
Proposed model (2014)	507	651	836	906	1,163	1,492
Data	186	261	335	359	434	509

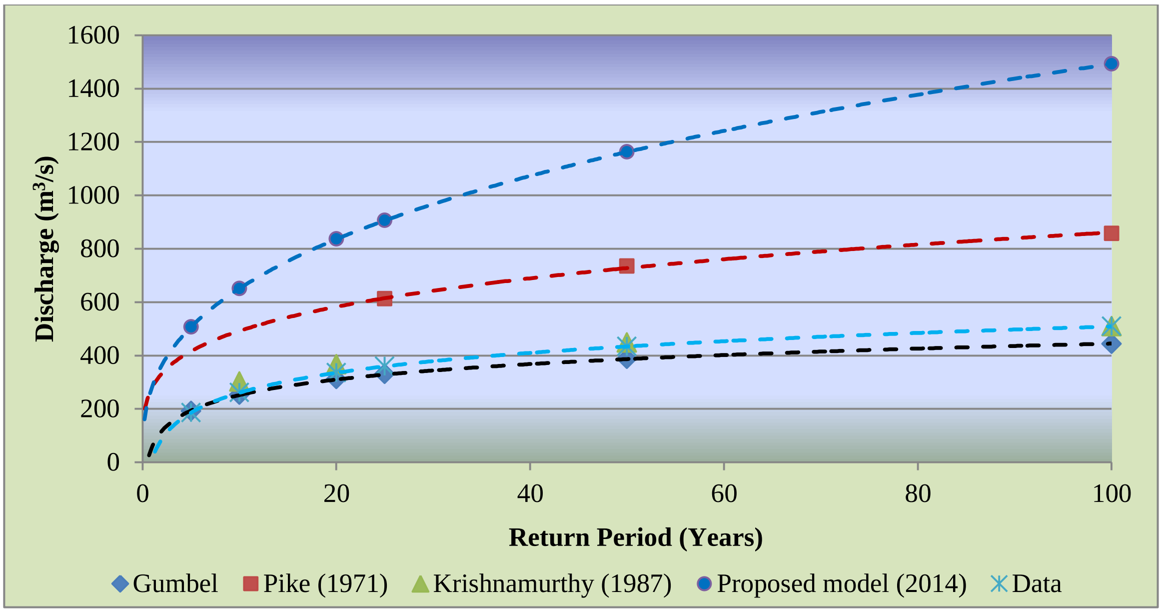

Figure 80: Graphical presentation of flood flows of Lilongwe River

Secondly, it is believed that upon occurrence of floods, much of the water is captured at Kamuzu Dam I and Kamuzu Dam II before the full magnitude of the flood can be gauged at RGS 4.D.4. Even so, the Old Town Bridge and the Bridge on the Presidential Way have been overtopped at least twice since 1977 (Water Department, 2014). In their calculation of the 100-year flood for the Lilongwe River at Malingunde with a basin area of 763km^2 and which is upstream of Old Town (RGS 4.D.4), Sogreah (2010) came up with a flood magnitude of 1,301m^3/s. This means therefore the 100-year flood for the Lilongwe River at Old Town is more than this figure which agrees with the results seen in Table 25 and Figure 80.

Table 26 and Figure 81 show results of estimates for the T-year flood for the Dwangwa

River in Kasungu District. The basin area is 2,980km^2 and even though the western part of the basin is in low-rainfall region, it also has some of its tributaries in the wetter southern slopes of the Viphya Highlands.

The design flood for the M1 Road Bridge at Dwangwa can be taken as 2,136m^3/s as this should be expected once in 100 years on average without the bridge being overtopped. The confidence placed on the information provided by the proposed method, is based on the fact that this station from which the data were obtained has had an automatic water level recorder which provided absolute maximum flows to define the rating curve.

Table 26: Computed flood flows for the Dwangwa River using available methods

DWANGWA 6.C.1 (2,980 km^2)						
Proposer	**Return Period (Years)**					
	5	**10**	**20**	**25**	**50**	**100**
Gumbel	142	177	211	222	255	287
Pike (1971)	-	-	-	773	927	1082
Krishnamurthy (1987)	-	383	464	-	569	646
Proposed model (2014)	726	932	1,197	1,297	1,664	2,136
Data	137	179	221	235	277	319

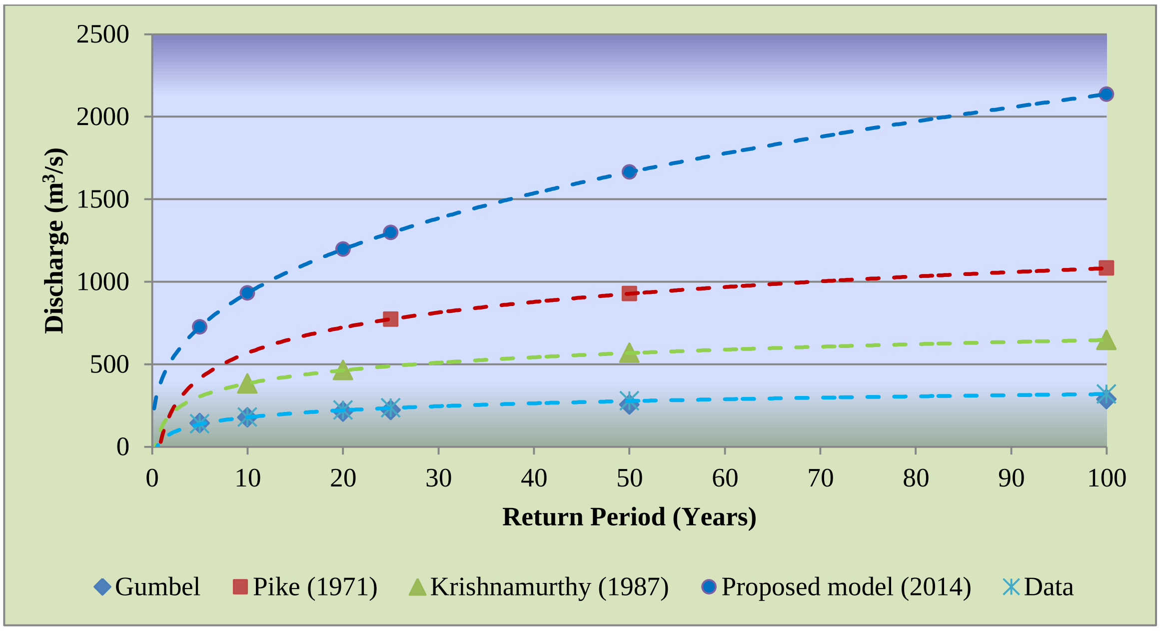

Figure 81: Graphical presentation of flood flows of Dwangwa River

The proposed method is seen to provide high estimates of the T-year flood flows for the Bua at S53 Road Bridge (Table 27 and Figure 82). With a total basin area of 10,600km^2

and with a prolonged storm engulfing the basin, huge floods of such high magnitudes should be expected. The Bua River is known to have washed away the Bua Rice Irrigation Scheme destroying the head works in the process which led to the complete rehabilitation of this scheme of national importance.

In its Socio-Economic Profile (Malawi Government (2010a) the Nkhotakota District Council states that, "While the water discharges in all the rivers in the district have been fluctuating it has been observed that the runoff had been increasing. It should be mentioned that there is high erosion rate in the upper parts of the district that can be attributed to deforestation and marginal land cultivation. The sediments carried due to soil erosion are deposited in the lower river course. The deposits (siltation) contribute to the high water runoff". This statement manifests to the objective of this work which is to reduce land degradation so as not to accelerate the generation of floods both in magnitude and frequency.

Table 27: Computed flood flows for Bua River using available methods

BUA 5.C.1 (10,600 km^2)						
Proposer	**Return Period (Years)**					
	5	**10**	**20**	**25**	**50**	**100**
Gumbel	832	1058	1275	1343	1555	1766
Pike (1971)	-	-	-	1458	1749	2041
Krishnamurthy (1987)	-	732	886	-	1086	1234
Proposed model (2014)	1,930	2,477	3,179	3,445	4,422	5,675
Data	812	1094	1375	1466	1748	2029

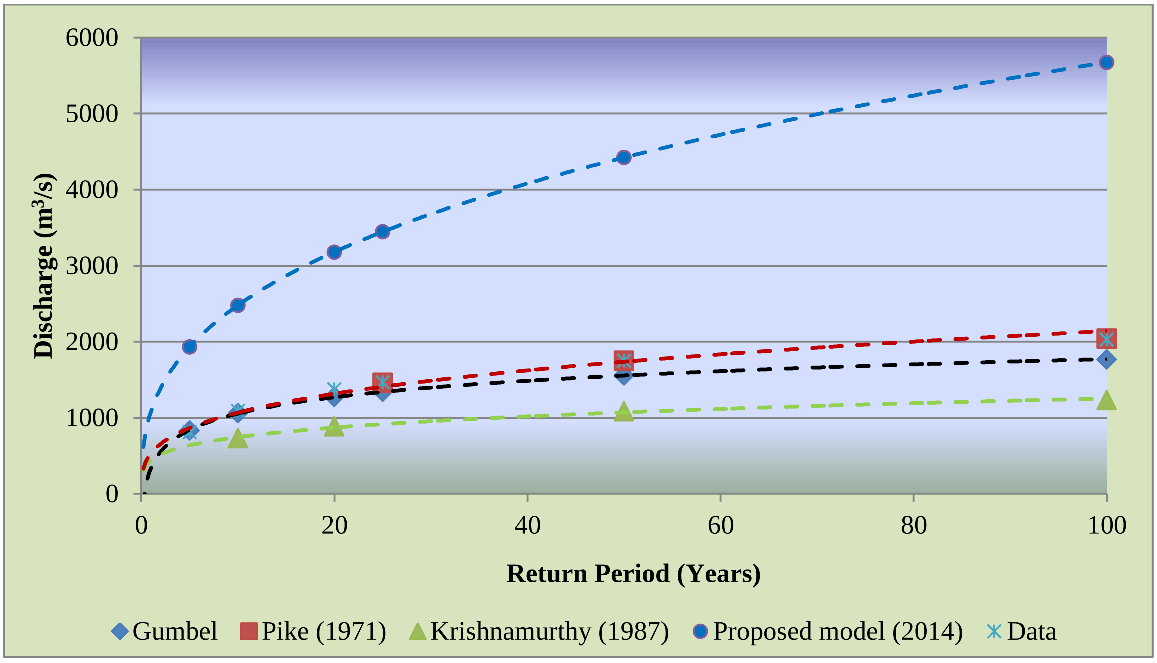

Figure 82: Graphical presentation of flood flows of Bua River

It must be concluded and noted that the T-year flood obtained using the proposed method takes into account that the flood will likely be reached but will not be exceeded once in those years on average and therefore any structures built or constructed using that design life are safe.

4.5 Recommendations

4.5.1 Use of the Regionalised Flood Frequency Model

The flood frequency model that has been developed can be used for the estimation of flood flows on both gauged and ungauged cathments within the Central Region of Malawi and it is important because it provides knowledge on where to set boundaries for settlements in areas close to river systems and to plan for the design life of hydraulic structures. The model should not be used for the rivers of the south and north because it is not yet clear if those rivers can pass the homogeneity test with the rivers of the Central Region.

In designing hydraulic and other structures such as farm drainage, airfileds and levées, it is important for the design engineer to choose the correct project life. Designing a low-traffic road for 100 years may not be cost effective just as designing a medium and high dam for 20 years may be dangerous and could cost people's lives and property should there be a dam break within that period because of dam failure. The recommended design criteria for hydraulic structures is provided by Chow (1988) and is presented in Table 28.

Table 28: Design Criteria for hydraulic structures

No.	Type of Hydraulic Structure	Return Period (Years)
1.	**Highway Culverts**	
	Low traffic	5 – 10
	Medium traffic	10 – 25
	High traffic	50 – 100
2.	**Highway Bridges**	
	Secondary roads	10 – 50
	Primary roads	50 – 100
3	**Farm Drainage**	
	Culverts	5 – 50
	Ditches	5 – 50
4.	**Urban Drainage**	
	Storm sewers in small cities	2 – 25
	Storm sewers in large cities	25 – 50
5.	**Airfields**	
	Low traffic	5 – 10
	Medium traffic	10 – 25
	High traffic	50 – 100
6.	**Levées**	
	On farm	2 – 50
	Around cities	50 – 200
7.	**Dams with no possibility of causing hazards**	
	Small dams	50 – 100
	Medium dams	100+
	Large dams	-
8.	**Dams with possibility of causing hazards**	
	Small dams	100+
	Medium dams	-
	Large dams	-
9.	**Dams with high possibility of causing hazards**	
	Small dams	-
	Medium dams	-
	Large dams	-

Source: Chow (1988) in Srinivas, V. V. (2012)

4.6 Communities' livelihoods, experiences and their perception of floods

In an attempt to understand how communities live and learn of their experiences with floods a field survey was conducted in seven river basins of Lifidzi, Luwazi, Lipimbi, Mtiti, Bua, Rusa and Dwangwa[1] where consultations were made with people living in flood-prone and potential areas of flooding. Annex III shows the interview questions while Annex IV presents the corresponding consolidated responses. It was also the intention of the survey to assess how floods affect their social life and what economic benefits and/or hardships they experience. The survey extended to exploring their objective assessment on what needs to be done in securing a sustainable environment within the region which could, to an extent, reduce the degree and frequency of floods and flooding within river basins.

In all the seven river basins, it became clear that floods have devastating impacts on the environment and have had severe influence on the lives of the people living in these areas. Along the lakeshore basins in Salima for instance, it was learnt that crops are usually destroyed and the river channels scoured thereby widening the river. In some cases, houses are destroyed or inundated. Over the plateau, it was learnt that during floods, crops such as tobacco may be harvested using boats (Kanyenda, 2014) in order to rescue the remaining little harvest that is remaining. In Kasungu North, villages have moved to higher ground because of the exceedingly high water levels that ensue when the Dwangwa River is in flood (Jangiya, 2014).

Asked if they know of any potential benefits that are associated with floods, some respondents said that there are no benefits from floods since they just bring havoc to communities. Other respondents however indicated that floods are good because after they are gone, there is moisture that is left behind that people use for planting crops.

Among the interviewees, those on the plateau especially within the Bua and Dwangwa River Basins have been affected by floods in recent times where crops and houses were destroyed and had to move their homes to safe places. Nonetheless, they indicated that when the Rusa River and the Dwangwa River are in flood, water can still reach close to their homes as happened in 1971 and 2006 respectively. When the Dwangwa River was in flood in 2006, they had their roofs blown away by high winds which were associated with the rainfall that caused the floods. Asked what responses were taken by them or any

[1] Note that some of these river basins such as Mtiti and Rusa are within a super basin like Bua River Basin.

organisation or institution to alleviate their suffering, they indicated that nothing was done and no one assisted them. For those families that were interviewed and live along the lakeshore, they said that they were not personally affected but floods occurred downstream close to the river mouths affecting homes in that area. Almost all the respondents looked to the government to assist them during flood disasters and showed remorse at the way they suffer during flood incidents when asked what must be done during such incidences.

It became very clear during these surveys that not many people are aware of the root causes of floods and flooding. Some of the interviewees said that the main cause of floods and flooding is too much rain and nothing else. In this regard, they meant that environmental degradation played no part in influencing floods and flooding of river basins.

However, some said that, “it is due to cutting down of trees near river banks and cultivating along the margins of the river channel”. Asked if cutting of trees in the middle and upper stages of the river basin would have any influence on flooding, they vehemently said, “No”. Wanting to know about the frequency of floods and flooding in their areas, it was found that some basins such as Rusa, floods of varying magnitudes occur almost every year with the year 2006 having recorded the highest flood as far as they can remember. In other areas such as in the Dwangwa River Basin people live in fear as floods can occur any time during the rainy season.

A diversity of ideas on how to deal with floods and flooding was received from the respondents apart from those that said they had no idea at all. Some of the respondents said that the best solution to deal with these events would have to be the planting of bananas, reeds and bamboos <u>within</u> the river channel (Saidi, 2014). Others had rudimentary knowledge of the possible solution as they advocated for planting trees along the river banks and stopping cultivation thereon.

Investigations on the economic aspects affecting or associated with the communities involved wanting to know their main sources of food and household income, their economic standing, whether they are happy or not and what ought to be done to improve their lives and welfare. Among the communities living along the lakeshore, the major food and cash crops were maize, groundnuts, soya and cotton while on the plateau they consisted of maize, soya, groundnuts, beans and pigeon peas as the major food crops with tobacco standing as the principal cash earner.

Except for only one respondent who happened to have retired from the civil service, the majority had grown these crops since their teens and have lived with this tradition ever since. Some of the respondents said that their way of life was improving and these were those from the plateau within the tobacco-growing belt while those along the lakeshore said their welfare was on a nose dive.

Figure 83: Andrew Phiri of Zelembe Village Kasungu, at his tobacco shed

Note: The shed is constructed of indigenous tree species as can be seen with a closer look to the right. More poles can be seen in the background.

Among the tobacco-growing communities, all of them said they grow burley tobacco and the method they use is sun-curing the tobacco in the barns. This involves constructing adequate sheds for the crop they expect to harvest and usually the construction and/or rehabilitation of these sheds is done on yearly basis. One respondent said she was contemplating growing flue-cured tobacco during the 2014 – 2015 tobacco growing season[2].

Both burley and flue-cured tobacco require a great deal of wood for curing the green leaf

[2] Flue-cured tobacco demands a lot of wood for curing the green leaf and because none of the communities own their own wood plots, they either buy from the forest reserves (usually very rare) or cut indigenous wood species from the remaining local secondary forest.

and in most cases this wood is obtained from the river banks (as was stated by one of the respondents within the Bua River Basin) or from the local forest. In most cases the medium-sized and large tobacco-growing companies usually obtain their wood from designated eucalyptus forests or they have their own forests of exotic tree species which are planted and grown within the tobacco estate premises. For the small tobacco farmers who are in their thousands, the wood for curing tobacco most often consists of indigenous tree species usually obtained from within their locality. The tobacco sheds are constructed or rehabilitated every year causing great pressure on the forest resources within the region. During the surveys, this assertion was manifested when a young tobacco grower was constructing his shed for the next season (see Figure 83).

Most of the interviewees showed no signs of any affluence despite having been engaged in the tobacco industry for many years and there was a distinct difference between the communities of the lakeshore plain and those of the plateau. In terms of their annual household income, those from the lakeshore region showed annual incomes of less than MK100, 000[3] while the families on the plateau indicated annual earnings in excess of this figure with some close to half a million Malawi Kwacha. All the respondents said that they were not happy with their economic standing in society. In this regard, they suggested that government or any financial institution or organisation should avail them with loans so that instead of concentrating on tobacco they should go into business. In this way they could earn money on a daily basis rather than waiting for a year when they have to go to the Auction Floors.

Unfortunately, some respondents said that they had no idea what can be done to improve their lives and therefore they were going to continue to grow tobacco as they see that there are no alternatives to this engagement as a source of household income. There were also others who said that there is need to diversify the crops they grow and government should continue with the *One cow/goat per Family Programme*. In this way they could earn money through selling milk or beef. Their main constraint towards enhancing their lives was initial capital to diversify.

Another area of interest was about their knowledge on sustainable environmental management. Asked whether they thought their activities such as growing tobacco had an influence on floods and flooding following deforestation, some said they did not know while others were affirmative. They said that cutting down of trees had a profound

[3] 1 US$ was about MK721.57 by September, 2016

influence on the environment and they do not support cutting down of tree needed for the construction of tobacco sheds. This is why, they said, floods were occurring frequently in recent times as (in their own words), "We have destroyed nature."

It was also of interest by the researcher to know how indigenous knowledge systems can be used in predicting floods when respondents said that indigenous knowledge is rich within their localities but it cannot be used in predicting when a flood will occur and of what magnitude. "Floods are natural events which must be expected and there is no way one can predict their occurrence" (Saidi, 2014; Waili, 2014).

One other important finding during these surveys was that the rural (suffice to say that this also may include urban) communities have no knowledge of the Malawian laws that relate to environmental management. Respondents during the surveys said that "only the bosses in Lilongwe know of these laws and we are not aware of them". The only law they know of, they said, was not to cut down trees and to plant trees when one has been cut down. It follows from this finding that awareness of the existing environmental statues is much wanting and government ought to translate the English laws into vernacular languages as briefs which could be distributed among communities so that they are aware of the importance of sustainable environmental management. Respondents for instance said that government seems not to be keen to "educate" communities on natural resources management.

Pursuant to the assertion above, the researcher enquired what efforts or level of participation they were taking in sustainably managing the environment when some of the respondents said none. Others said that they took no part and admitted to be part of the problem since they cut down trees for their trade in tobacco. Finally, there were those others who confidently said they play a part by planting trees even though no such trees were seen by the researcher within the neighbourhood for apparently, according to the respondents, the trees had been "eaten by termites" (Phiri, 2014).

4.7 Environment and Development

The SADC Regional Water Policy (2006) recognises the important role that water can play in development. It ought not to be a menace but can be a useful resource if well managed. The policy states that, "Member States shall commit themselves to protect human life, livestock, property and the environment against the effects of water-related natural and human-induced disasters". It goes on to say, "Commitment to this policy should be demonstrated by creating conditions that reduce the risk of disaster, such as appropriate land-use planning, settlement policies and climate change strategies (page 33)”.

Since floods will continue to occur, Malawians should begin to live with floods and regard them as a vital natural resource able to provide a positive contribution towards socio-economic development for the country. Water should not necessarily be a curse – and therefore it only needs to be tamed and sustainably managed. In this regard and realising that the country experiences some of the worst droughts within the southern African region, government must consider accelerating the rehabilitation of some of the existing 700 small dams constructed in the 1960s in addition to building more dams across the region (and elsewhere within the country) so that they can hold back excess water during times of floods. This water can therefore be used for irrigation during the dry season and fulfil the aspirations of the Greenbelt Initiative spelt out within the Malawi Growth and Development Strategy.

4.8 Conclusion

Chapter 4 has focussed on addressing three important areas. These areas are the following:

- Documentation of flood events that have occurred in the region and their impacts;
- Examination of river flows; and
- Development of a Regional Flood Frequency Model for the Central Region.

The gravity of suffering of some communities in the Central Region has been demonstrated by a chronology of flood events that occurred from 2000 to 2003 which involved loss of crops, livestock and damage to buildings, homes and bridges. This information is important because it shows that a small economy such as Malawi cannot afford to regularly be subjected to such negative events without taking some mitigation measures on board. It has also been discussed how government and other organisations react to these incidences, which is on ad hoc basis. In this regard, and as one of the mitigation measures which also addresses the requirement of the Malawi Water Policy (2005) which states that no one must cultivate below the 100m contour from the river bank, a flood frequency model must be developed which can determine where to settle, cultivate or how high a bridge should be built.

As stated in the introduction of this chapter, the development of the flood frequency model must be based on data of good quality and length. Pursuant to this requirement, the researcher has presented the hydrographs of the rivers used in this work the majority of which show continuous records of annual instantaneous maximum flows. Good fits of the relationship between the annual flood flows and their reduced variates are also observed.

Finally, a “regional” flood frequency model for the river basins of the Central Region of Malawi has been developed and can now be used for any gauged or ungauged catchment within this region to determine the T-year flood in cumecs. This model is qualified by a regional homogeneity test that has been carried out for the regular gauging stations and their flows in the Central Region and the test has shown a strong relationship between all the station, meaning that the river basins are homogeneous and therefore the model is applicable anywhere in the region.

The researcher also learnt, through audience he had with the people in some of the river basins on the lakeshore plain and on the Plateau, that people know that they are responsible for land degradation through deforestation due to poverty and that they thought tobacco has not assisted them in their economic status. This statement agrees well with the findings of Bunderson and Hayes (1997). It is also accepted that while floods were previously common particularly in the districts of Chikwawa and Nsanje in southern Malawi, they are now spreading to other regions such as the North and the Centre (UNICEF, 2014). The developed flood model will therefore be useful in assessing which areas below which need not be settled or cultivated to avoid loss of life and property.

CHAPTER 5
CONCLUSION

5. Introduction

Extreme weather events can cause a host of social, economic, cultural, environmental as well as political problems and challenges. Problems arising from extreme weather events are said to have the potential to lead to the collapse of a whole economy (UNEP, 2006) such as that of Malawi. Considering that Malawi is already one of the poorest economies of the world, floods are negatively affecting the country's development agenda as resources are diverted to finance unforeseen and unplanned programmes of rehabilitation, reconstruction and provision of assistance to affected communities.

Being a poor country and primarily dependent on agriculture, it is expected that with a rising population there is likely to be further environmental degradation arising out of exploitation of natural resources. The National Environment Policy (Malawi Government, 2004) clearly states that, "Poverty is one of the root causes of environmental degradation in Malawi and is at the core of the government's development agenda for the foreseeable future. Its alleviation is critical to natural resource conservation, protection and sustainable utilisation (page 8)". Therefore those in authority must know that social equity, economic efficiency and ecological sustainability are all intertwined (GWP, 2000) to ensure that the government's commitment to natural resources conservation, protection and sustainable utilisation are achieved.

This research work was principally aimed at addressing three research questions which were:

(a) To explore where, in the Central Region of Malawi floods have occurred, what their impacts have been and document a sample of them to illustrate those impacts;

(b) To examine if flood frequency models developed outside the country are relevant to Malawi and whether they can be used in estimating the T-year floods for the Central Region of the country; and

(c) Whether it is possible to develop a new flood frequency model specifically for the Central Region of Malawi.

These three research questions, led to the formulation of the research objectives which were to:

(i) Document flood occurrences in the Central Region;
(ii) Examine existing flood frequency models; and
(iii) Develop of a new flood frequency model.

These three research objectives were considered using literature review, hydrological data collection, processing and analysis supplemented by observations from the river basins under study.

5.1 Documenting flood occurrences in the Central Region

While floods have been common in the Lower Shire Valley districts of Chikwawa and Nsanje, the floods have also occurred in other districts of Malawi both in the Northern and Central Region. The study area of this research work, the Central Region has experienced floods of various magnitudes some of which have destroyed roads, bridges and culverts while others have damages people's homes, destroyed their crops and killed their livestock.

These properties suffer the devastating impacts of floods because they are located in flood-prone areas. Settlements and people's farms that are located in such areas stand the risk of being damaged or destroyed when floods occur and this has been illustrated by a sample of devastating floods that occurred from 2000 to 2003. This documentation of floods during this period is meant to make a case for finding a mitigation measure in the region in the form of a flood frequency model. Further documentation of such floods is necessary by the Department of Disaster Management Affairs (DoDMA) as well as the Water Department for future reference, analysis, planning and decision making.

Having reviewed and documented the occurrence of floods in the Central Region and their impacts on people and the environment, the first objective of this research work is therefore achieved.

5.2 Examining existing flood frequency models

It has been explained in this work that flood occurrence is dependent on geophysical and climatic parameters or characteristics. For instance, occurrence of floods in semi-arid areas cannot be the same as their occurrence in monsoon-type climatic regions. In this regard therefore flood frequency models developed for river basins with semi-arid climatic conditions will be based on hydrological and other geophysical parameters and characteristic typical to that region. The soils, vegetation, slope, shape and other physical characteristics of a river basin are important in determining flood characteristics and these characteristics may not necessarily be the same or similar to those that may be found in a river basin located in a monsoon-dominated climatic region.

Differences in geophysical parameters and/or characteristics of river basins do therefore influence how frequent floods may occur and at what magnitude. Some of the “regional” flood frequency formula that have previously been developed for Malawi for instance by Pike (1971, have shown that at least three “regions” occur in Malawi with different “growth factors”. Similarly the “regional” formula proposed by Krishnamurthy in 1987 also provides three different hydrological “regions” some of which may occur within the same administrative region of Malawi.

No single flood frequency model is universal because some river basins are heterogeneous while others are homogeneous. In homogeneous river basins, a flood frequency model can then be developed and applied to the whole “region” covering the river basins. A test of homogeneity is however necessary.

5.3 Development of a new flood frequency model

Floods will continue to take place within the country’s river basins but no one can tell exactly when a flood of magnitude Q will occur. Their impacts on people and the economy are more often distressing than beneficial in settled areas but floods can be managed depending on availability of resources, skills and human power. The occurrence of a flood of magnitude Q can however be predicted that it will occur at least once *on average* after so many years. This study has come up with a new flood frequency model which may now be used for the river basins of the Central Region of Malawi for the design of bridges, roads, dams, culverts and other structures as well as for the use in the planning of settlements within the river basins.

This work, *Development of a Flood-Frequency Model for the River Basins of the Central Region of Malawi as a Tool for Engineering Design and Disaster Preparedness in Flood-Prone Areas* adds value to the tasks of many present and future engineers and planners who in the course of executing their work would have found it exceedingly difficult to estimate the magnitude of a flood of a given return period in both gauged and ungauged catchments. The simplicity of the model will also assist the engineers and planners to find quick solutions to their hydrological and hydraulic pursuits. The authenticity of this model is based on the fact that the river basins of the region have all been subjected to a comprehensive homogeneity test that certifies that the rivers bear similar geophysical characteristic influencing floods.

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Appendix A: Population of Central Region by Districts (1998 – 2014)

District/ Region	Year																
	1998	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Dedza	483519	495405	510530	526874	544334	562823	582289	602696	624028	646292	669511	693714	718919	745124	772311	800446	829726
Dowa	409127	415526	424609	434693	445662	457426	469924	483110	496954	511448	526604	542445	558987	576230	594150	612691	631879
Kasungu	477334	495375	513562	531914	550568	569581	589019	608917	629278	650103	671391	693143	715354	738010	761090	784594	808673
Lilongwe	1337354	1390635	1450600	1513798	1580012	1649049	1720784	1795112	1871958	1951278	2033049	2117261	2203911	2292995	2384512	2478478	2575533
Mchinji	322613	332008	343414	355443	368090	381335	395171	409590	424588	440162	456314	473044	490356	508252	526733	545804	565601
Nkhotakota	227872	235559	243215	250939	258827	266909	275213	283761	292556	301604	310909	320480	330321	340429	350792	361394	372314
Ntchisi	166603	173215	179919	186703	193625	200712	207997	215501	223223	231165	239328	247712	256313	265117	274098	283227	292552
Salima	247297	257185	267167	277277	287576	298099	308882	319947	331308	342979	354977	367318	380013	393067	406479	420254	434508
Central Region	3671719	3794908	3933016	4077641	4228694	4385934	4549279	4718634	4893893	5075031	5262083	5455117	5654174	5859224	6070165	6286888	6510786

Source: Data from the National Statistical Office, Zomba

Appendix B: Absolute Maximum Flows and Flood Analysis for Namikokwe 3.E.2

Year	Q (m^3/s)	Ranked series	Rank (m)	T (n + 1/m)	P (1/n + 1)	P' {1 – (1/n + 1)}	y = -ln [-ln (1-1/T)]
1970/71	9.11	96.9	1	31.0	0.032	0.968	3.426
1971/72	14.2	83.7	2	15.5	0.064	0.936	2.716
1972/73	11.6	70.2	3	10.3	0.097	0.903	2.282
1973/74	37.3	63.2	4	7.75	0.129	0.871	1.980
1974/75	25.1	59.3	5	6.20	0.161	0.839	1.740
1975/76	32.9	57.4	6	5.17	0.194	0.806	1.534
1976/77	13.6	47.7	7	4.43	0.226	0.774	1.362
1977/78	25.6	38.1	8	3.88	0.258	0.742	1.209
1978/79	**n.a**	37.3	9	3.44	0.290	0.710	1.072
1979/80	11.6	33.3	10	3.10	0.322	0.678	0.945
1980/81	32.9	32.9	11	2.82	0.355	0.645	0.824
1981/82	96.9	32.9	12	2.58	0.387	0.613	0.714
1982/83	70.2	32.6	13	2.38	0.419	0.581	0.611
1983/84	59.3	32.2	14	2.21	0.452	0.548	0.508
1984/85	16.1	31.5	15	2.07	0.484	0.516	0.413
1985/86	83.7	30.5	16	1.94	0.516	0.484	0.321
1986/87	33.3	27.2	17	1.82	0.548	0.452	0.231
1987/88	63.2	25.6	18	1.72	0.581	0.419	0.139
1988/89	57.4	25.1	19	1.63	0.612	0.388	0.055
1989/90	38.1	20.9	20	1.55	0.645	0.355	-0.035
1990/91	20.9	16.1	21	1.48	0.677	0.323	-0.122
1991/92	5.99	14.2	22	1.41	0.710	0.290	-0.213
1992/93	32.6	13.6	23	1.35	0.742	0.258	-0.304
1993/94	6.90	11.6	24	1.29	0.774	0.226	-0.397
1994/95	32.2	11.6	25	1.24	0.806	0.194	-0.495
1995/96	27.2	9.11	26	1.19	0.839	0.161	-0.602
1996/97	31.5	6.90	27	1.15	0.871	0.129	-0.717
1997/98	47.7	5.99	28	1.11	0.903	0.097	-0.847
1998/99	**n.a**	4.82	29	1.07	0.935	0.065	-1.005
1999/00	4.10	4.10	30	1.03	0.968	0.032	-1.236
2000/01	4.82						
2001/02	30.5						

Appendix C: Absolute Maximum Flows and Flood Analysis for Livulezi 3.E.3

Year	Q (m^3/s)	Ranked series	Rank (m)	T (n + 1/m)	P (1/n + 1)	P' {1 – (1/n + 1)}	y = -ln [-ln (1-1/T)]
1970/71	314	433	1	33.0	0.030	0.970	3.491
1971/72	82.2	384	2	17.5	0.057	0.943	2.836
1972/73	46.8	314	3	11.0	0.091	0.909	2.349
1973/74	32.9	261	4	8.25	0.121	0.879	2.048
1974/75	84.1	234	5	6.60	0.152	0.848	1.802
1975/76	**n.a**	184	6	5.50	0.182	0.818	1.605
1976/77	112	169	7	4.71	0.212	0.788	1.434
1977/78	**n.a**	112	8	4.12	0.243	0.757	1.279
1978/79	63.1	112	9	3.67	0.272	0.728	1.147
1979/80	73.2	84.1	10	3.30	0.303	0.697	1.019
1980/81	184	82.2	11	3.00	0.333	0.667	0.904
1981/82	261	73.2	12	2.75	0.364	0.636	0.793
1982/83	169	68.9	13	2.54	0.394	0.606	0.691
1983/84	234	63.1	14	2.36	0.424	0.576	0.595
1984/85	433	53.6	15	2.22	0.450	0.550	0.514
1985/86	384	46.8	16	2.06	0.485	0.515	0.410
1986/87	45.5	45.5	17	1.94	0.515	0.485	0.324
1987/88	45.5	45.5	18	1.83	0.546	0.454	0.236
1988/89	38.6	38.6	19	1.74	0.575	0.425	0.156
1989/90	53.6	32.9	20	1.65	0.606	0.394	0.071
1990/91	68.9	8.55	21	1.57	0.637	0.363	0.013
1991/92	**n.a**	6.79	22	1.50	0.667	0.333	-0.095
1992/93	**n.a**	5.80	23	1.43	0.699	0.301	-0.183
1993/94	**n.a**	5.69	24	1.38	0.725	0.275	-0.255
1994/95	**n.a**	5.65	25	1.32	0.757	0.243	-0.347
1995/96	**n.a**	5.49	26	1.27	0.787	0.213	-0.436
1996/97	5.65	5.10	27	1.22	0.820	0.180	-0.539
1997/98	5.80	5.05	28	1.18	0.847	0.153	-0.630
1998/99	4.60	4.97	29	1.14	0.877	0.123	-0.740
1999/00	4.97	4.84	30	1.10	0.909	0.091	-0.874
2000/01	5.69	4.60	31	1.06	0.943	0.057	-1.052
2001/02	2.55	2.55	32	1.03	0.971	0.029	-1.264
2002/03	8.55						

2003/04	5.10
2004/05	6.79
2005/06	4.84
2006/07	5.49
2007/08	5.05

Appendix D: Absolute Maximum Flows and Flood Analysis for Namikokwe 3.E.5

Year	Q (m^3/s)	Ranked series	Rank (m)	T (n + 1/m)	P (1/n + 1)	P' {1 – (1/n + 1)}	y = -ln [-ln (1-1/T)]
1970/71	126	149	1	26.0	0.038	0.962	3.251
1971/72	4.01	147	2	13.0	0.077	0.923	2.524
1972/73	147	126	3	8.67	0.115	0.885	2.102
1973/74	149	105	4	6.60	0.152	0.848	1.802
1974/75	35.3	79.2	5	5.20	0.192	0.808	1.546
1975/76	49.0	58.8	6	4.33	0.231	0.769	1.337
1976/77	58.8	58.3	7	3.71	0.269	0.731	1.160
1977/78	49.0	49.0	8	3.25	0.308	0.692	0.999
1978/79	48.5	49.0	9	2.89	0.346	0.654	0.856
1979/80	58.3	48.5	10	2.60	0.385	0.615	0.721
1980/81	8.25	35.3	11	2.36	0.424	0.576	0.595
1981/82	**n.a**	30.6	12	2.17	0.461	0.539	0.481
1982/83	5.33	17.3	13	2.00	0.500	0.500	0.366
1983/84	5.95	13.0	14	1.86	0.538	0.462	0.258
1984/85	**n.a**	11.9	15	1.73	0.578	0.422	0.148
1985/86	4.11	11.5	16	1.62	0.617	0.383	0.041
1986/87	5.20	8.25	17	1.53	0.654	0.346	0.060
1987/88	2.01	7.61	18	1.44	0.694	0.306	-0.169
1988/89	11.9	5.95	19	1.37	0.730	0.270	-0.270
1989/90	11.5	5.33	20	1.30	0.769	0.231	-0.382
1990/91	13.03	5.20	21	1.24	0.806	0.194	-0.495
1991/92	**n.a**	4.11	22	1.18	0.847	0.153	-0.630
1992/93	17.3	4.01	23	1.13	0.885	0.115	-0.771
1993/94	**n.a**	3.41	24	1.08	0.926	0.074	-0.957
1994/95	3.41	2.01	25	1.04	0.962	0.038	-1.185
1995/96	79.2						
1996/97	105						
1997/98	**n.a**						
1998/99	**n.a**						
1999/00	**n.a**						
2000/01	30.6						
2001/02	**n.a**						

2002/03	7.61
2003/04	**n.a**
2004/05	**n.a**
2005/06	**n.a**
2006/07	**n.a**
2007/08	**n.a**
2008/09	**n.a**

Appendix E: Absolute Maximum Flows and Flood Analysis for Linthipe 4.B.1

Year	Q (m^3/s)	Ranked series	Rank (m)	T (n + 1/m)	P (1/n + 1)	P' {1 – (1/n + 1)}	y = -ln [-ln (1-1/T)]
1970/71	730	3691	1	37.0	0.027	0.973	3.600
1971/72	420	3403	2	18.5	0.054	0.946	2.891
1972/73	347	3306	3	12.3	0.081	0.919	2.471
1973/74	668	1797	4	9.25	0.108	0.892	2.169
1974/75	623	1713	5	7.40	0.135	0.865	1.931
1975/76	668	1713	6	6.17	0.162	0.838	1.733
1976/77	601	1658	7	5.28	0.189	0.811	1.563
1977/78	945	1433	8	4.62	0.216	0.784	1.413
1978/79	615	1259	9	4.11	0.243	0.757	1.279
1979/80	591	1058	10	3.70	0.270	0.730	1.156
1980/81	1058	945	11	3.36	0.298	0.702	1.039
1981/82	**n.a**	730	12	3.08	0.325	0.675	0.934
1982/83	**n.a**	682	13	2.85	0.351	0.649	0.838
1983/84	268	681	14	2.64	0.379	0.621	0.741
1984/85	300	668	15	2.47	0.405	0.595	0.655
1985/86	**n.a**	668	16	2.31	0.433	0.567	0.567
1986/87	260	658	17	2.18	0.459	0.541	0.487
1987/88	246	623	18	2.06	0.485	0.515	0.410
1988/89	277	615	19	1.95	0.513	0.487	0.329
1989/90	1433	601	20	1.85	0.540	0.460	0.253
1990/91	584	591	21	1.76	0.568	0.432	0.175
1991/92	210	590	22	1.68	0.595	0.405	0.101
1992/93	590	584	23	1.61	0.621	0.379	0.030
1993/94	682	420	24	1.54	0.649	0.351	-0.046
1994/95	180	412	25	1.48	0.676	0.324	-0.120
1995/96	3403	400	26	1.42	0.704	0.296	-0.197
1996/97	1259	347	27	1.37	0.730	0.270	-0.270
1997/98	1797	300	28	1.32	0.758	0.242	-0.350
1998/99	3306	277	29	1.28	0.781	0.219	-0.418
1999/00	412	268	30	1.23	0.813	0.187	-0.517
2000/01	400	260	31	1.19	0.840	0.160	-0.606
2001/02	658	246	32	1.16	0.862	0.138	-0.683

2002/03	1713	210	33	1.12	0.893	0.107	-0.804
2003/04	152	180	34	1.09	0.917	0.083	-0.912
2004/05	174	174	35	1.06	0.943	0.057	-1.052
2005/06	1658	152	36	1.03	0.971	0.029	-1.264
2006/07	1713						
2007/08	3691						
2008/09	681						

Appendix F: Absolute Maximum Flows and Flood Analysis for Linthipe 4.B.3

Year	Q (m^3/s)	Ranked series	Rank (m)	T (n + 1/m)	P (1/n + 1)	P' {1 – (1/n + 1)}	y = -ln [-ln (1-1/T)]
1970/71	539	701	1	34.0	0.029	0.971	3.526
1971/72	136	558	2	17.0	0.059	0.941	2.800
1972/73	50.3	539	3	11.3	0.088	0.912	2.385
1973/74	151	326	4	8.50	0.118	0.882	2.075
1974/75	300	300	5	6.80	0.147	0.853	1.834
1975/76	701	300	6	5.67	0.176	0.834	1.642
1976/77	259	296	7	4.86	0.206	0.794	1.467
1977/78	326	296	8	4.25	0.235	0.765	1.317
1978/79	207	288	9	3.78	0.264	0.736	1.182
1979/80	300	286	10	3.40	0.294	0.706	1.055
1980/81	**n.a**	261	11	3.09	0.324	0.676	0.938
1981/82	122	259	12	2.83	0.353	0.647	0.831
1982/83	296	258	13	2.61	0.383	0.617	0.728
1983/84	123	239	14	2.43	0.411	0.589	0.636
1984/85	66.0	207	15	2.27	0.440	0.560	0.545
1985/86	296	177	16	2.12	0.472	0.528	0.448
1986/87	261	173	17	2.00	0.500	0.500	0.366
1987/88	162	162	18	1.89	0.529	0.471	0.284
1988/89	558	156	19	1.79	0.559	0.441	0.200
1989/90	286	151	20	1.70	0.588	0.412	0.120
1990/91	288	136	21	1.62	0.617	0.383	0.041
1991/92	51.0	123	22	1.54	0.649	0.351	-0.046
1992/93	258	122	23	1.48	0.676	0.324	-0.120
1993/94	45.8	120	24	1.42	0.704	0.296	-0.197
1994/95	83.6	108	25	1.36	0.735	0.265	-0.284
1995/96	156	94.4	26	1.31	0.763	0.237	-0.364
1996/97	239	83.6	27	1.26	0.794	0.206	-0.457
1997/98	94.4	82.4	28	1.21	0.826	0.174	-0.557
1998/99	120	82.4	29	1.17	0.855	0.145	-0.658
1999/00	**n.a**	66.0	30	1.13	0.885	0.115	-0.771
2000/01	108	51.0	31	1.10	0.909	0.091	-0.874
2001/02	**n.a**	50.3	32	1.06	0.943	0.057	-1.052

2002/03	173	45.8	33	1.03	0.971	0.029	-1.264
2003/04	**n.a**						
2004/05	177						
2005/06	**n.a**						
2006/07	82.4						
2007/08	82.4						
2008/09	**n.a**						

Appendix G: Absolute Maximum Flows and Flood Analysis for Linthipe 4.B.9

Year	Q (m^3/s)	Ranked series	Rank (m)	T (n + 1/m)	P (1/n + 1)	P' {1 – (1/n + 1)}	y = -ln [-ln (1-1/T)]
1970/71	**n.a**	1992	1	36.0	0.027	0.973	3.598
1971/72	**n.a**	1837	2	18.0	0.055	0.945	2.872
1972/73	**n.a**	1826	3	12.0	0.083	0.917	2.446
1973/74	**n.a**	1757	4	9.00	0.111	0.889	2.140
1974/75	1837	1439	5	7.20	0.139	0.861	1.899
1975/76	1439	1439	6	6.00	0.167	0.833	1.700
1976/77	1757	1266	7	5.14	0.194	0.806	1.534
1977/78	1439	1170	8	4.50	0.222	0.778	1.382
1978/79	1826	741	9	4.00	0.250	0.750	1.246
1979/80	1170	738	10	3.60	0.278	0.722	1.122
1980/81	1992	694	11	3.27	0.306	0.694	1.007
1981/82	551	659	12	3.00	0.333	0.667	0.904
1982/83	530	647	13	2.77	0.361	0.639	0.803
1983/84	647	647	14	2.57	0.389	0.611	0.708
1984/85	647	645	15	2.40	0.417	0.583	0.617
1985/86	210	596	16	2.25	0.444	0.556	0.533
1986/87	312	551	17	2.12	0.472	0.528	0.448
1987/88	234	530	18	2.00	0.500	0.500	0.366
1988/89	738	490	19	1.89	0.529	0.471	0.284
1989/90	243	462	20	1.80	0.555	0.445	0.211
1990/91	283	456	21	1.71	0.585	0.415	0.128
1991/92	102	427	22	1.64	0.610	0.390	0.060
1992/93	283	427	23	1.56	0.641	0.359	0.024
1993/94	462	340	24	1.50	0.667	0.333	-0.095
1994/95	115	312	25	1.44	0.694	0.306	-0.169
1995/96	427	283	26	1.38	0.725	0.275	-0.255
1996/97	645	283	27	1.33	0.752	0.248	-0.332
1997/98	490	243	28	1.28	0.781	0.219	-0.418
1998/99	741	234	29	1.24	0.806	0.194	-0.495
1999/00	200	210	30	1.20	0.833	0.167	-0.582
2000/01	456	200	31	1.16	0.862	0.138	-0.683
2001/02	694	115	32	1.12	0.893	0.107	-0.804

2002/03	659	102	33	1.09	0.917	0.083	-0.912
2003/04	86.4	86.4	34	1.06	0.943	0.057	-1.052
2004/05	1266	86.4	35	1.03	0.971	0.029	-1.264
2005/06	427						
2006/07	340						
2007/08	86.4						
2008/09	596						

Appendix H: Absolute Maximum Flows and Flood Analysis for Lilongwe 4.C.2

Year	Q (m^3/s)	Ranked series	Rank (m)	T (n + 1/m)	P (1/n + 1)	P' {1 – (1/n + 1)}	y = -ln [-ln (1-1/T)]
1970/71	304	947	1	30.0	0.033	0.967	3.394
1971/72	133	865	2	15.0	0.067	0.933	2.668
1972/73	110	845	3	10.0	0.100	0.900	2.250
1973/74	401	834	4	7.50	0.133	0.867	1.947
1974/75	171	630	5	6.00	0.167	0.833	1.700
1975/76	**n.a**	509	6	5.00	0.200	0.800	1.500
1976/77	122	503	7	4.28	0.234	0.766	1.322
1977/78	480	484	8	3.75	0.267	0.733	1.169
1978/79	87.6	480	9	3.33	0.300	0.700	1.031
1979/80	384	454	10	3.00	0.333	0.667	0.904
1980/81	294	401	11	2.73	0.366	0.664	0.893
1981/82	395	395	12	2.50	0.400	0.600	0.672
1982/83	158	384	13	2.31	0.433	0.567	0.567
1983/84	351	380	14	2.14	0.467	0.533	0.463
1984/85	274	357	15	2.00	0.500	0.500	0.366
1985/86	264	351	16	1.88	0.532	0.468	0.275
1986/87	865	304	17	1.76	0.568	0.432	0.175
1987/88	291	294	18	1.67	0.599	0.401	0.090
1988/89	834	291	19	1.58	0.633	0.367	0.002
1989/90	503	274	20	1.50	0.667	0.333	-0.095
1990/91	357	264	21	1.43	0.699	0.301	-0.183
1991/92	189	189	22	1.36	0.735	0.265	-0.284
1992/93	630	171	23	1.30	0.769	0.231	-0.382
1993/94	845	158	24	1.25	0.800	0.200	-0.476
1994/95	135	135	25	1.20	0.833	0.167	-0.582
1995/96	947	133	26	1.15	0.870	0.130	-0.713
1996/97	380	122	27	1.11	0.901	0.099	-0.838
1997/98	454	110	28	1.07	0.934	0.066	-1.000
1998/99	484	87.6	29	1.03	0.971	0.029	-1.264
1999/00	509						
2000/01	**n.a**						
2001/02	**n.a**						

Appendix I: Absolute Maximum Flows and Flood Analysis for Lilongwe 4.D.4

Year	Q (m^3/s)	Ranked series	Rank (m)	T (n + 1/m)	P (1/n + 1)	P' {1 – (1/n + 1)}	y = -ln [-ln (1-1/T)]
1970/71	156	398	1	35.0	0.029	0.971	3.526
1971/72	18.9	335	2	17.5	0.057	0.943	2.836
1972/73	10.7	250	3	11.7	0.086	0.914	2.409
1973/74	107	219	4	8.75	0.114	0.886	2.112
1974/75	51.9	214	5	7.00	0.143	0.857	1.869
1975/76	64.5	205	6	5.83	0.171	0.829	1.674
1976/77	60.6	181	7	5.00	0.200	0.800	1.500
1977/78	398	174	8	4.38	0.229	0.771	1.347
1978/79	70.2	172	9	3.89	0.257	0.743	1.214
1979/80	205	156	10	3.50	0.286	0.714	1.088
1980/81	214	146	11	3.18	0.314	0.686	0.976
1981/82	219	124	12	2.92	0.343	0.657	0.867
1982/83	335	124	13	2.69	0.371	0.629	0.769
1983/84	35.4	124	14	2.50	0.400	0.600	0.672
1984/85	69.3	119	15	2.33	0.429	0.571	0.579
1985/86	250	107	16	2.19	0.457	0.543	0.493
1986/87	21.9	98.2	17	2.06	0.486	0.514	0.407
1987/88	27.9	93.1	18	1.94	0.514	0.486	0.326
1988/89	98.2	91.1	19	1.84	0.543	0.457	0.244
1989/90	174	83.4	20	1.75	0.571	0.429	0.167
1990/91	21.5	70.2	21	1.67	0.600	0.400	0.087
1991/92	14.9	69.3	22	1.59	0.629	0.371	0.008
1992/93	124	64.5	23	1.52	0.657	0.343	-0.068
1993/94	14.9	60.6	24	1.46	0.686	0.314	-0.147
1994/95	8.40	51.9	25	1.40	0.714	0.286	-0.224
1995/96	93.1	35.4	26	1.35	0.743	0.257	-0.306
1996/97	**n.a**	27.9	27	1.30	0.771	0.229	-0.388
1997/98	181	21.9	28	1.25	0.800	0.200	-0.476
1998/99	124	21.5	29	1.21	0.829	0.171	-0.569
1999/00	119	18.9	30	1.17	0.857	0.143	-0.665
2000/01	172	14.9	31	1.13	0.886	0.114	-0.775

2001/02	124	14.9	32	1.09	0.914	0.086	-0.897
2002/03	146	10.7	33	1.06	0.943	0.057	-1.052
2003/04	**n.a**	8.40	34	1.03	0.971	0.029	-1.264
2004/05	83.4						
2005/06	**n.a**						
2006/07	**n.a**						
2007/08	91.1						
2008/09							

Appendix J: Absolute Maximum Flows and Flood Analysis for Lilongwe 4.D.6

Year	Q (m^3/s)	Ranked series	Rank (m)	T (n + 1/m)	P (1/n + 1)	P' {1 – (1/n + 1)}	y = -ln [-ln (1-1/T)]
1970/71	**n.a**	256	1	19.0	0.053	0.947	2.910
1971/72	**n.a**	250	2	9.50	0.105	0.895	2.199
1972/73	7.35	231	3	6.33	0.158	0.842	1.760
1973/74	109	214	4	4.75	0.210	0.790	1.445
1974/75	33.9	214	5	3.80	0.263	0.737	1.187
1975/76	126	188	6	3.17	0.315	0.685	0.972
1976/77	77.0	179	7	2.71	0.369	0.631	0.776
1977/78	250	170	8	2.34	0.427	0.573	0.585
1978/79	53.1	126	9	2.11	0.474	0.526	0.442
1979/80	214	109	10	1.90	0.526	0.474	0.292
1980/81	179	77.0	11	1.73	0.578	0.422	0.148
1981/82	214	60.2	12	1.58	0.633	0.367	-0.002
1982/83	256	53.1	13	1.46	0.685	0.315	-0.144
1983/84	25.2	45.9	14	1.36	0.735	0.265	-0.284
1984/85	45.9	37.2	15	1.27	0.787	0.213	-0.436
1985/86	170	33.9	16	1.19	0.840	0.160	-0.606
1986/87	37.2	25.2	17	1.12	0.893	0.107	-0.804
1987/88	60.2	7.35	18	1.05	0.952	0.048	-1.111
1988/89	231						
1989/90	188						
1990/91	**n.a**						

Appendix K: Absolute Maximum Flows and Flood Analysis for Lingadzi 4.E.1

Year	Q (m^3/s)	Ranked series	Rank (m)	T (n + 1/m)	P (1/n + 1)	P' {1 – (1/n + 1)}	y = -ln [-ln (1-1/T)]
1970/71	480	480	1	28.0	0.036	0.964	3.306
1971/72	164	442	2	14.0	0.071	0.929	2.608
1972/73	185	434	3	9.33	0.107	0.893	2.179
1973/74	320	409	4	7.00	0.143	0.857	1.869
1974/75	442	384	5	5.60	0.179	0.821	1.623
1975/76	360	360	6	4.67	0.214	0.786	1.424
1976/77	**n.a**	320	7	4.00	0.250	0.750	1.246
1977/78	**n.a**	279	8	3.50	0.286	0.714	1.088
1978/79	237	275	9	3.11	0.322	0.678	0.945
1979/80	96.6	237	10	2.80	0.357	0.643	0.817
1980/81	279	237	11	2.54	0.394	0.606	0.691
1981/82	237	216	12	2.33	0.429	0.571	0.579
1982/83	275	185	13	2.15	0.465	0.535	0.469
1983/84	86.6	178	14	2.00	0.500	0.500	0.366
1984/85	178	164	15	1.87	0.535	0.465	0.267
1985/86	68.4	163	16	1.75	0.571	0.429	0.169
1986/87	384	98.7	17	1.65	0.606	0.394	0.071
1987/88	91.5	97.6	18	1.55	0.645	0.355	-0.035
1988/89	434	96.6	19	1.47	0.680	0.320	-0.130
1989/90	216	91.5	20	1.40	0.714	0.286	-0.224
1990/91	97.6	86.6	21	1.33	0.752	0.248	-0.332
1991/92	63.5	86.6	22	1.27	0.787	0.213	-0.436
1992/93	163	68.4	23	1.22	0.820	0.180	-0.539
1993/94	86.6	63.5	24	1.17	0.855	0.145	-0.658
1994/95	**n.a**	60.4	25	1.12	0.893	0.107	-0.804
1995/96	**n.a**	46.0	26	1.08	0.926	0.074	-0.957
1996/97	**n.a**	11.8	27	1.04	0.962	0.038	-1.185
1997/98	98.7						
1998/99	**n.a**						
1999/00	**n.a**						
2000/01	46.0						
2001/02	11.8						
2002/03	409						

2003/04	**n.a**
2004/05	60.4
2005/06	**n.a**
2006/07	**n.a**

Appendix L: Absolute Maximum Flows and Flood Analysis for Lingadzi 4.E.2

Year	Q (m^3/s)	Ranked series	Rank (m)	T (n + 1/m)	P (1/n + 1)	P' {1 – (1/n + 1)}	y = -ln [-ln (1-1/T)]
1970/71	53.6	152	1	31.0	0.032	0.968	3.426
1971/72	35.9	152	2	15.5	0.064	0.936	2.716
1972/73	25.0	142	3	10.3	0.097	0.903	2.282
1973/74	50.3	121	4	7.75	0.129	0.871	1.980
1974/75	54.6	59.6	5	6.20	0.161	0.839	1.740
1975/76	44.2	54.6	6	5.17	0.193	0.807	1.540
1976/77	33.6	54.6	7	4.43	0.226	0.774	1.362
1977/78	54.6	54.6	8	3.88	0.258	0.742	1.209
1978/79	19.9	54.1	9	3.44	0.291	0.709	1.067
1979/80	41.7	53.6	10	3.10	0.322	0.678	0.945
1980/81	54.6	50.3	11	2.82	0.355	0.645	0.824
1981/82	54.1	49.1	12	2.58	0.388	0.612	0.711
1982/83	47.4	47.4	13	2.38	0.420	0.580	0.607
1983/84	39.6	46.6	14	2.21	0.452	0.548	0.508
1984/85	36.3	44.2	15	2.07	0.483	0.517	0.416
1985/86	37.9	41.7	16	1.94	0.515	0.485	0.324
1986/87	39.6	39.6	17	1.82	0.549	0.451	0.228
1987/88	46.6	39.6	18	1.72	0.581	0.419	0.139
1988/89	59.6	37.9	19	1.63	0.613	0.387	0.052
1989/90	49.1	36.3	20	1.55	0.645	0.355	-0.035
1990/91	15.5	35.9	21	1.48	0.676	0.324	-0.120
1991/92	13.2	33.6	22	1.41	0.709	0.291	-0.211
1992/93	5.34	33.0	23	1.35	0.741	0.259	-0.301
1993/94	4.73	25.0	24	1.29	0.775	0.225	-0.400
1994/95	4.66	19.9	25	1.24	0.806	0.194	-0.495
1995/96	142	15.5	26	1.19	0.840	0.160	-0.606
1996/97	121	13.2	27	1.15	0.870	0.130	-0.713
1997/98	152	5.34	28	1.11	0.901	0.099	-0.838
1998/99	152	4.73	29	1.07	0.934	0.066	-1.000
1999/00	**n.a**	4.66	30	1.03	0.971	0.029	-1.264
2000/01	**n.a**						
2001/02	**n.a**						
2002/03	**n.a**						

2003/04	33.0
2004/05	**n.a**

Appendix M: Absolute Maximum Flows and Flood Analysis for Lumbadzi 4.F.6

Year	Q (m^3/s)	Ranked series	Rank (m)	T (n + 1/m)	P (1/n + 1)	P' {1 – (1/n + 1)}	y = -ln [-ln (1-1/T)]
1970/71	**n.a**	1350	1	22.0	0.045	0.955	3.078
1971/72	**n.a**	1185	2	11.0	0.091	0.909	2.350
1972/73	**n.a**	1056	3	7.33	0.136	0.864	1.923
1973/74	**n.a**	952	4	5.50	0.182	0.818	1.605
1974/75	38.6	684	5	4.40	0.227	0.773	1.357
1975/76	952	605	6	3.67	0.272	0.728	1.147
1976/77	**n.a**	547	7	3.14	0.318	0.682	0.960
1977/78	60.0	527	8	2.75	0.364	0.636	0.793
1978/79	684	234	9	2.44	0.410	0.590	0.639
1979/80	123	217	10	2.20	0.454	0.546	0.502
1980/81	198	198	11	2.00	0.500	0.500	0.366
1981/82	1056	166	12	1.83	0.546	0.454	0.236
1982/83	217	135	13	1.69	0.592	0.408	0.109
1983/84	547	123	14	1.57	0.637	0.363	0.013
1984/85	67.6	67.6	15	1.47	0.680	0.320	-0.130
1985/86	17.4	67.6	16	1.38	0.725	0.275	-0.255
1986/87	49.6	60.0	17	1.29	0.775	0.225	-0.400
1987/88	527	49.6	18	1.22	0.820	0.180	-0.539
1988/89	1185	38.6	19	1.16	0.862	0.138	-0.683
1989/90	35.0	35.0	20	1.10	0.909	0.091	-0.874
1990/91	605	17.4	21	1.05	0.952	0.048	-1.111
1991/92	234						
1992/93	67.6						
1993/94	166						
1994/95	135						
1995/96	1350						
1996/97	**n.a**						

Appendix N: Absolute Maximum Flows and Flood Analysis for Bua 5. C. 1

Year	Q (m^3/s)	Ranked series	Rank (m)	T (n + 1/m)	P (1/n + 1)	P' {1 – (1/n + 1)}	y = -ln [-ln (1-1/T)]
1970/71	893	1703	1	38.0	0.026	0.974	3.636
1971/72	196	1402	2	19.0	0.053	0.947	2.910
1972/73	1703	1093	3	12.7	0.079	0.921	2.497
1973/74	642	1042	4	9.50	0.105	0.895	2.200
1974/75	702	903	5	7.60	0.112	0.888	2.130
1975/76	739	893	6	6.33	0.158	0.842	1.760
1976/77	201	752	7	5.43	0.184	0.816	1.593
1977/78	903	739	8	4.75	0.210	0.790	1.445
1978/79	752	727	9	4.22	0.237	0.763	1.307
1979/80	314	706	10	3.80	0.263	0.737	1.187
1980/81	472	702	11	3.45	0.289	0.711	1.076
1981/82	216	642	12	3.17	0.316	0.684	0.968
1982/83	258	626	13	2.92	0.342	0.658	0.871
1983/84	129	622	14	2.71	0.368	0.632	0.779
1984/85	1093	556	15	2.53	0.395	0.605	0.688
1985/86	535	539	16	2.34	0.421	0.589	0.636
1986/87	176	535	17	2.23	0.447	0.553	0.524
1987/88	240	535	18	2.11	0.474	0.526	0.442
1988/89	622	528	19	2.00	0.500	0.500	0.366
1989/90	1402	472	20	1.90	0.526	0.474	0.292
1990/91	195	463	21	1.81	0.553	0.447	0.217
1991/92	246	444	22	1.73	0.579	0.421	0.145
1992/93	374	374	23	1.65	0.605	0.395	0.074
1993/94	257	314	24	1.58	0.636	0.364	-0.010
1994/95	240	258	25	1.52	0.658	0.342	-0.070
1995/96	539	257	26	1.46	0.684	0.316	-0.142
1996/97	727	248	27	1.41	0.710	0.290	-0.213
1997/98	248	246	28	1.34	0.737	0.263	-0.289
1998/99	1042	244	29	1.31	0.763	0.237	-0.364
1999/00	244	240	30	1.27	0.789	0.211	-0.442
2000/01	535	240	31	1.22	0.816	0.184	-0.526
2001/02	528	216	32	1.19	0.842	0.158	-0.612
2002/03	556	201	33	1.15	0.868	0.132	-0.706

2003/04	**n.a**	196	34	1.12	0.895	0.105	-0.813
2004/05	**n.a**	195	35	1.08	0.921	0.079	-0.931
2005/06	444	176	36	1.06	0.947	0.053	-1.078
2006/07	626	129	37	1.03	0.974	0.026	-1.295
2007/08	463						
2008/09	706						

Appendix O: Absolute Maximum Flows and Flood Analysis for Mtiti 5.D.3

Year	Q (m^3/s)	Ranked series	Rank (m)	T (n + 1/m)	P (1/n + 1)	P' {1 – (1/n + 1)}	y = -ln [-ln (1-1/T)]
1970/71	51.2	51.2	1	32.0	0.031	0.969	3.458
1971/72	11.8	50.4	2	16.0	0.062	0.938	2.749
1972/73	9.40	34.9	3	10.7	0.093	0.907	2.327
1973/74	29.1	32.4	4	8.00	0.125	0.875	2.013
1974/75	24.1	32.4	5	6.40	0.156	0.844	1.774
1975/76	**n.a**	31.3	6	5.33	0.188	0.812	1.569
1976/77	19.6	31.1	7	4.57	0.219	0.781	1.398
1977/78	31.1	29.1	8	4.00	0.250	0.750	1.246
1978/79	17.0	24.1	9	3.55	0.282	0.718	1.105
1979/80	19.6	22.8	10	3.20	0.312	0.688	0.984
1980/81	31.3	19.8	11	2.91	0.344	0.656	0.864
1981/82	50.4	19.6	12	2.67	0.374	0.626	0.758
1982/83	18.4	19.6	13	2.46	0.406	0.594	0.652
1983/84	22.8	18.4	14	2.28	0.438	0.562	0.551
1984/85	10.4	17.0	15	2.13	0.469	0.531	0.457
1985/86	15.5	15.8	16	2.00	0.500	0.500	0.366
1986/87	34.9	15.5	17	1.88	0.532	0.468	0.275
1987/88	15.8	11.8	18	1.78	0.562	0.438	0.192
1988/89	32.4	10.4	19	1.68	0.595	0.405	0.101
1989/90	32.4	9.40	20	1.60	0.625	0.375	0.019
1990/91	19.8	4.20	21	1.52	0.658	0.342	-0.070
1991/92	1.99	3.59	22	1.45	0.690	0.310	-0.158
1992/93	3.59	2.23	23	1.39	0.719	0.281	-0.238
1993/94	4.20	1.99	24	1.33	0.752	0.248	-0.332
1994/95	0.30	1.10	25	1.28	0.781	0.219	-0.418
1995/96	2.23	1.05	26	1.23	0.813	0.187	-0.517
1996/97	1.10	0.60	27	1.18	0.847	0.153	-0.630
1997/98	0.60	0.59	28	1.14	0.877	0.123	-0.740
1998/99	**n.a**	0.52	29	1.10	0.909	0.091	-0.874
1999/00	0.34	0.34	30	1.07	0.934	0.066	-1.000
2000/01	0.52	0.30	31	1.03	0.971	0.029	-1.264
2001/02	0.59						

Appendix P: Absolute Maximum Flows and Flood Analysis for Rusa 5.F.1

Year	Q (m^3/s)	Ranked series	Rank (m)	T (n + 1/m)	P (1/n + 1)	P' {1 – (1/n + 1)}	y = -ln [-ln (1-1/T)]
1970/71	13.5	193	1	32.0	0.031	0.969	3.458
1971/72	4.82	173	2	16.0	0.062	0.938	2.749
1972/73	0.90	154	3	10.7	0.093	0.907	2.327
1973/74	9.51	144	4	8.00	0.125	0.875	2.013
1974/75	7.02	119	5	6.40	0.156	0.844	1.774
1975/76	7.02	110	6	5.33	0.188	0.812	1.569
1976/77	6.22	101	7	4.57	0.219	0.781	1.398
1977/78	13.5	62.7	8	4.00	0.250	0.750	1.246
1978/79	9.58	56.0	9	3.55	0.282	0.718	1.105
1979/80	10.7	50.1	10	3.20	0.312	0.688	0.984
1980/81	11.9	46.8	11	2.91	0.344	0.656	0.864
1981/82	24.8	40.8	12	2.67	0.374	0.626	0.758
1982/83	2.34	24.8	13	2.46	0.406	0.594	0.652
1983/84	1.53	21.7	14	2.28	0.438	0.562	0.551
1984/85	1.81	15.2	15	2.13	0.469	0.531	0.457
1985/86	119	14.6	16	2.00	0.500	0.500	0.366
1986/87	21.7	13.5	17	1.88	0.532	0.468	0.275
1987/88	40.8	13.5	18	1.78	0.562	0.438	0.192
1988/89	62.7	11.9	19	1.68	0.595	0.405	0.101
1989/90	46.8	10.7	20	1.60	0.625	0.375	0.019
1990/91	15.2	9.58	21	1.52	0.658	0.342	-0.070
1991/92	14.6	9.51	22	1.45	0.690	0.310	-0.158
1992/93	56	8.01	23	1.39	0.719	0.281	-0.238
1993/94	50.1	7.02	24	1.33	0.752	0.248	-0.332
1994/95	8.01	7.02	25	1.28	0.781	0.219	-0.418
1995/96	173	6.22	26	1.23	0.813	0.187	-0.517
1996/97	144	4.82	27	1.18	0.847	0.153	-0.630
1997/98	110	2.34	28	1.14	0.877	0.123	-0.740
1998/99	**n.a**	1.81	29	1.10	0.909	0.091	-0.874
1999/00	**n.a**	1.53	30	1.07	0.934	0.066	-1.000
2000/01	193	0.90	31	1.03	0.971	0.029	-1.264
2001/02	**n.a**						
2002/03	**n.a**						

2003/04	101
2004/05	154
2005/06	**n.a**

Appendix Q: Absolute Maximum Flows and Flood Analysis for Dwangwa 6.C.1

Year	Q (m^3/s)	Ranked series	Rank (m)	T (n + 1/m)	P (1/n + 1)	P' {1 – (1/n + 1)}	y = -ln [-ln (1-1/T)]
1970/71	116	232	1	37.0	0.027	0.973	3.598
1971/72	27.1	216	2	18.5	0.054	0.946	2.891
1972/73	61.5	174	3	12.3	0.081	0.919	2.471
1973/74	93.0	172	4	9.25	0.108	0.892	2.169
1974/75	116	156	5	7.40	0.135	0.865	1.931
1975/76	106	145	6	6.17	0.162	0.838	1.733
1976/77	16.5	145	7	5.28	0.189	0.811	1.563
1977/78	118	144	8	4.62	0.216	0.784	1.413
1978/79	70.2	141	9	4.11	0.243	0.757	1.279
1979/80	172	139	10	3.70	0.270	0.730	1.156
1980/81	51.3	118	11	3.36	0.297	0.703	1.043
1981/82	23.3	118	12	3.08	0.324	0.676	0.938
1982/83	141	116	13	2.85	0.351	0.649	0.838
1983/84	43.7	116	14	2.64	0.378	0.622	0.745
1984/85	83.9	106	15	2.47	0.405	0.595	0.655
1985/86	145	97.8	16	2.31	0.432	0.568	0.570
1986/87	71.5	93.0	17	2.18	0.459	0.541	0.487
1987/88	97.8	92.6	18	2.06	0.486	0.514	0.407
1988/89	232	83.9	19	1.95	0.514	0.486	0.326
1989/90	139	82.8	20	1.85	0.540	0.460	0.253
1990/91	19.0	81.9	21	1.76	0.567	0.433	0.178
1991/92	22.8	81.7	22	1.68	0.594	0.406	0.104
1992/93	145	75.7	23	1.61	0.622	0.378	0.028
1993/94	81.9	74.6	24	1.54	0.649	0.351	-0.046
1994/95	74.6	71.5	25	1.48	0.676	0.324	-0.120
1995/96	174	70.2	26	1.42	0.703	0.297	-0.194
1996/97	**n.a**	62.2	27	1.37	0.730	0.270	-0.270
1997/98	82.8	61.5	28	1.32	0.757	0.243	-0.347
1998/99	62.2	51.3	29	1.28	0.784	0.216	-0.427
1999/00	34.2	43.7	30	1.23	0.811	0.189	-0.510
2000/01	144	34.2	31	1.19	0.838	0.162	-0.599
2001/02	81.7	27.1	32	1.16	0.865	0.135	-0.694
2002/03	216	23.3	33	1.12	0.892	0.108	-0.800

2003/04	**n.a**	22.8	34	1.09	0.919	0.081	-0.922
2004/05	92.6	19.0	35	1.06	0.946	0.054	-1.071
2005/06	**n.a**	16.5	36	1.03	0.973	0.027	-1.284
2006/07	156						
2007/08	75.7						
2008/09	118						

Appendix R: Absolute Maximum Flows and Flood Analysis for Mpasadzi 6.C.5

Year	Q (m^3/s)	Ranked series	Rank (m)	T (n + 1/m)	P (1/n + 1)	P' {1 – (1/n + 1)}	y = -ln [-ln (1-1/T)]
1970/71	105	153	1	27.0	0.037	0.963	3.278
1971/72	35.1	143	2	13.5	0.074	0.926	2.565
1972/73	68.1	105	3	9.00	0.111	0.889	2.140
1973/74	33.8	98.3	4	6.75	0.148	0.852	1.832
1974/75	34.5	91.9	5	5.40	0.185	0.815	1.587
1975/76	98.3	83.4	6	4.50	0.222	0.778	1.382
1976/77	91.9	68.1	7	3.86	0.259	0.741	1.205
1977/78	**n.a**	60.8	8	3.38	0.296	0.704	1.047
1978/79	**n.a**	49.6	9	3.00	0.333	0.667	0.904
1979/80	23.3	38.5	10	2.70	0.370	0.630	0.772
1980/81	143	35.1	11	2.45	0.408	0.592	0.646
1981/82	15.2	35.0	12	2.25	0.444	0.556	0.533
1982/83	23.0	34.5	13	2.08	0.481	0.519	0.422
1983/84	4.47	33.8	14	1.93	0.518	0.482	0.315
1984/85	7.89	32.4	15	1.80	0.555	0.445	0.211
1985/86	83.4	23.5	16	1.69	0.592	0.408	0.109
1986/87	18.2	23.3	17	1.59	0.629	0.371	0.008
1987/88	14.8	23.0	18	1.50	0.667	0.333	-0.095
1988/89	153	18.2	19	1.42	0.704	0.296	-0.197
1989/90	38.5	16.3	20	1.35	0.741	0.259	-0.301
1990/91	8.20	15.2	21	1.28	0.781	0.219	-0.418
1991/92	6.48	14.8	22	1.23	0.813	0.187	-0.517
1992/93	35.0	8.20	23	1.17	0.855	0.145	-0.658
1993/94	60.8	7.89	24	1.12	0.893	0.107	-0.804
1994/95	49.6	6.48	25	1.08	0.926	0.074	-0.957
1995/96	16.3	4.47	26	1.04	0.962	0.038	-1.185
1996/97	32.4						
1997/98	23.5						
1998/99	**n.a**						

Appendix S: Absolute Maximum Flows and Flood Analysis for Chirua 15.A.4

Year	Q (m^3/s)	Ranked series	Rank (m)	T (n + 1/m)	P (1/n + 1)	P' {1 – (1/n + 1)}	y = -ln [-ln (1-1/T)]
1970/71	39.8	1589	1	21.0	0.048	0.952	3.012
1971/72	61.4	1299	2	10.5	0.095	0.905	2.304
1972/73	26.7	478	3	7.00	0.143	0.857	1.869
1973/74	134	446	4	5.25	0.190	0.810	1.557
1974/75	99.4	422	5	4.20	0.238	0.762	1.303
1975/76	**n.a**	339	6	3.50	0.286	0.714	1.088
1976/77	**n.a**	226	7	3.00	0.333	0.667	0.904
1977/78	**n.a**	159	8	2.62	0.382	0.618	0.731
1978/79	**n.a**	148	9	2.33	0.429	0.571	0.579
1979/80	**n.a**	134	10	2.10	0.476	0.524	0.436
1980/81	**n.a**	105	11	1.91	0.524	0.476	0.298
1981/82	**n.a**	99.4	12	1.75	0.571	0.429	0.167
1982/83	**n.a**	80.2	13	1.62	0.617	0.383	0.041
1983/84	**n.a**	68.9	14	1.50	0.667	0.333	-0.095
1984/85	**n.a**	64.1	15	1.40	0.714	0.286	-0.224
1985/86	14.0	61.4	16	1.31	0.763	0.237	-0.364
1986/87	46.5	46.5	17	1.24	0.806	0.194	-0.495
1987/88	64.1	39.8	18	1.17	0.855	0.145	-0.658
1988/89	80.2	26.7	19	1.10	0.909	0.091	-0.874
1989/90	226	14.0	20	1.05	0.952	0.048	-1.111
1990/91	478						
1991/92	105						
1992/93	68.9						
1993/94	422						
1994/95	148						
1995/96	446						
1996/97	339						
1997/98	1299						
1998/99	159						
1999/00	1589						
2000/01	**n.a**						
2001/02	**n.a**						

Appendix T: Absolute Maximum Flows and Flood Analysis for Lingadzi 15.A.8

Year	Q (m^3/s)	Ranked series	Rank (m)	T (n + 1/m)	P (1/n + 1)	P' {1 – (1/n + 1)}	y = -ln [-ln (1-1/T)]
1970/71	**n.a**	1383	1	34.0	0.029	0.971	3.526
1971/72	**n.a**	606	2	17.0	0.059	0.941	2.800
1972/73	**n.a**	587	3	11.3	0.088	0.912	2.385
1973/74	284	573	4	8.50	0.118	0.882	2.075
1974/75	31.4	559	5	6.80	0.147	0.853	1.839
1975/76	103	481	6	5.67	0.176	0.824	1.642
1976/77	**n.a**	464	7	4.86	0.206	0.794	1.467
1977/78	376	406	8	4.25	0.235	0.765	1.317
1978/79	107	406	9	3.78	0.264	0.736	1.182
1979/80	103	395	10	3.40	0.294	0.706	1.055
1980/81	559	376	11	3.09	0.323	0.677	0.941
1981/82	1383	369	12	2.83	0.353	0.647	0.831
1982/83	587	284	13	2.61	0.382	0.618	0.731
1983/84	38.9	277	14	2.43	0.412	0.588	0.633
1984/85	117	267	15	2.27	0.441	0.559	0.542
1985/86	481	181	16	2.12	0.470	0.530	0.454
1986/87	159	159	17	2.00	0.500	0.500	0.366
1987/88	47.4	145	18	1.89	0.529	0.471	0.284
1988/89	606	126	19	1.79	0.559	0.441	0.200
1989/90	145	122	20	1.70	0.588	0.412	0.120
1990/91	395	120	21	1.62	0.618	0.382	0.038
1991/92	277	117	22	1.54	0.647	0.353	-0.040
1992/93	126	107	23	1.48	0.676	0.324	-0.120
1993/94	267	103	24	1.42	0.706	0.294	-0.202
1994/95	464	103	25	1.36	0.735	0.265	-0.284
1995/96	573	47.4	26	1.31	0.765	0.235	-0.370
1996/97	369	38.9	27	1.26	0.794	0.206	-0.457
1997/98	181	31.4	28	1.21	0.824	0.176	-0.552
1998/99	122	27.9	29	1.17	0.853	0.147	-0.651
1999/00	120	21.0	30	1.13	0.882	0.118	-0.759
2000/01	406	5.73	31	1.10	0.912	0.088	-0.888
2001/02	21	4.32	32	1.06	0.941	0.059	-1.040
2002/03	406	3.35	33	1.03	0.970	0.030	-1.255

2003/04	**n.a**
2004/05	**n.a**
2005/06	3.35
2006/07	5.73
2007/08	27.9
2008/09	4.32

Appendix U: Absolute Maximum Flows and Flood Analysis for Kaombe 15.B.13

Year	Q (m^3/s)	Ranked series	Rank (m)	T (n + 1/m)	P (1/n + 1)	P' {1 – (1/n + 1)}	y = -ln [-ln (1-1/T)]
1970/71	**n.a**	1086	1	24.0	0.042	0.958	3.149
1971/72	**n.a**	1056	2	12.0	0.083	0.917	2.446
1972/73	**n.a**	1049	3	8.00	0.125	0.875	2.013
1973/74	**n.a**	940	4	6.00	0.167	0.833	1.700
1974/75	**n.a**	940	5	4.80	0.208	0.792	1.456
1975/76	**n.a**	638	6	4.00	0.250	0.750	1.246
1976/77	**n.a**	636	7	3.43	0.292	0.708	1.063
1977/78	**n.a**	569	8	3.00	0.333	0.667	0.904
1978/79	**n.a**	527	9	2.67	0.374	0.626	0.758
1979/80	**n.a**	476	10	2.40	0.417	0.583	0.617
1980/81	**n.a**	393	11	2.18	0.459	0.541	0.487
1981/82	**n.a**	342	12	2.00	0.500	0.500	0.366
1982/83	**n.a**	299	13	1.85	0.540	0.460	0.253
1983/84	**n.a**	282	14	1.71	0.585	0.415	0.128
1984/85	**n.a**	265	15	1.60	0.625	0.375	0.019
1985/86	**n.a**	247	16	1.50	0.667	0.333	-0.095
1986/87	6.71	147	17	1.41	0.709	0.291	-0.211
1987/88	103	146	18	1.33	0.752	0.248	-0.332
1988/89	569	121	19	1.26	0.794	0.206	-0.457
1989/90	72.4	103	20	1.20	0.833	0.167	-0.582
1990/91	121	72.4	21	1.14	0.877	0.123	-0.740
1991/92	146	40.2	22	1.09	0.917	0.083	-0.912
1992/93	393	6.71	23	1.04	0.962	0.038	-1.185
1993/94	299						
1994/95	40.2						
1995/96	147						
1996/97	527						
1997/98	342						
1998/99	1049						
1999/00	1056						
2000/01	940						
2001/02	940						
2002/03	636						

2003/04	638
2004/05	476
2005/06	282
2006/07	247
2007/08	265
2008/09	1086

Annex I: Page 1 of the Application Form to conduct research

ETHICS APPLICATION FORM
for the
College of Agriculture and Environmental Sciences (CAES)
Unisa

UNISA

Application for Ethics approval to undertake a research project involving, animals, human participants, the environment, biomedical, other living organisms and/or genetically modified organisms

For Administrative Use
Application number: 2013/CAES/000

NAME OF APPLICANT: ELTON LAISI

Staff number/Student number: 49945785

Department: ENVIRONMENTAL SCIENCES

Title of study: A Flood-Frequency Model for the River Basins of the Central Region of Malawi as a Tool for Design and Preparedness in Flood-Prone Areas.

DECLARATION

The applicant/researcher(s) of this Ethics Application undertake(s) to treat all that has been stated in this application in a manner that is respectful of the rights and integrity of all research subjects, as stipulated in the UNISA Research Ethics Policy.

The applicant/researcher(s) undertakes to notify the Ethics Committee of the College of Agriculture and Environmental Sciences at Unisa if changes to the aforementioned proposal are effected.

The supervisor of the applicant approves of the Ethics submission and has assessed the content of the Ethics Application form before submission to the CAES Ethics Committee. The supervisor acknowledges that the proposal accompanying this application has served at the departmental research vetting committee and was approved.

Mr. Elton Laisi
Name of applicant (Title, Full Names & Surname)

Signature

October 16, 2013
Date

Dr. Geoffrey Chavula
Name of Supervisor if applicant is a student in CAES
(Title, Full Names & Surname)

Signature

16_October, 2013
Date

Annex II: Letter of Introduction

Tel. No. (265) 01 770 344/ 221
Fax No. (265) 01 773 737
Email : secretary@irriwater.org

Tikwere House
City Centre
Private Bag 390
Lilongwe 3
MALAWI

MINISTRY OF WATER DEVELOPMENT AND IRRIGATION

Ref: WDI/H/153

4th November, 2013

TO WHOM IT MAY CONCERN

Dear Sir/Madam,

This is to certify that Mr. Elton Laisi has been given authority by this office to carry out investigations relating to water resources in the Central Region particularly in the Districts of Dedza, Lilongwe, Mchinji, Salima, Dowa, Kasungu and Nkhotakota. These investigations are needed for his M.Sc (Environmental Management) research work he is doing with the University of South Africa on the causes and impacts of floods and flooding in the region and we are of the view that the findings from these investigations will be of great value and will assist in taking proactive measures in mitigating the impacts of floods on people and property.

Mr. Laisi will require conducting interviews with communities in the seven districts and taking photographs related to his research work and we kindly ask you to grant him all the necessary assistance that he may require while he is in your area.

Yours Sincerely,

S.C.Y. Maweru

SECRETARY FOR WATER DEVELOPMENT AND IRRIGATION

Annex III: Sample of completed answer sheet as recorded on September 13, 2014.

DISTRICT	RESPONDENT	VILLAGE	GRID REFERENCE	QUESTIONS	RESPONSES
		Social aspects related to communities			
Kasungu T.A Kaomba	Mai Mary Jangiya + Andrew Phiri	Zelembe	12°53'S 33°27'E	Negative impacts of floods	- Crops are eroded, little harvest, villages have now moved away from banks. We were near the river. Lost iron sheets during rains. 1971
				Positive impacts of floods	Moisture for crops use the river water for drinking
				How have floods affected you?	we lost many things — maize tobacco, chickens, iron sheets (storm) and houses destroyed.
				What did you lose?	(see above)
				What did you do?	Moved to high ground and when we moved floods came again.
				Who intervened and how?	No One.
				Was the intervention adequate?	N.A.
				Is this a better approach in dealing with disasters?	N.A.
				What do you think are	

				the causes of floods?	Too much rain; This is a big river so there is much water
				Is the frequency of floods increasing or was it a once-off incident?	The water comes every year but do not know if ↑ or ↓
				What should be done of these events and by whom?	Do not know.
		Economic aspects related to communities			
				What are your main food and cash crops?	Maize, Soya, groundnuts beans and tobacco.
				How long have you grown these crops?	Ever since we were born.
				Is there an increasing trend in income from the cash crop?	Decreasing due to prices of crops
				If it is tobacco that is the cash crop, what curing methods do you use?	We use sun curing as we only grow ~~bu~~ barley.
				Which areas do you get material for curing the tobacco?	From our garden (??)
				What livestock do you keep?	Goats, chickens
				What was your annual household income (last year)?	can't remember but not much.
				Is your economic status satisfactory?	No.
				What must be done to improve it far?	Organisations dealing with credit should assist us.
				What are your main	we cannot change

				constraints?	because we cannot diversify
		Environmental aspects related to communities			
				Do you think your activities on the environment do influence the levels of flooding?	No idea
				What are the main causes of floods in your view?	Too much rain
				Are there any indigenous knowledge systems that can be used in predicting floods?	None we know of
				If yes, what are they and can they be used with confidence?	N.A
				What must be done to reduce incidences and magnitudes of floods and their impacts?	N.A.
				Are you aware of the current laws governing natural resources management?	Yes - We should not burn charcoal; no cutting down of trees.
				What is your level of engagement in natural resources management and how has such engagement contributed to sustainability of resources?	We planted blue gum trees near our houses but termites have destroyed them

Annex IV: Questionnaire used in the Districts and Consolidated Responses

RIVER BASINS	QUESTIONS	RESPONSES
Social aspects related to communities		
	Negative impacts of floods	• Crops are usually destroyed and are carried away by floods; • There is also erosion of the river bed and river banks; • Communities are never at peace because they anticipate floods any time during the rainy season; • Houses are destroyed; • Sometimes communities harvest their tobacco before it matures to save it from getting lost to floods; • Little harvests are realised; • Our villages have now moved away from the flood plain.
	Positive impacts of floods	• None; • They bring moisture; • We are able to have water throughout the year
	How have floods affected you?	• No; • Our village was close to the river and we have moved away from the flood plain. However, sometimes the water still reaches close to the village; • Houses were destroyed; • We lost our crops especially tobacco, groundnuts and maize. We had to use boats to harvest some of the tobacco and maize which had shown signs of maturity

	What did you lose?	• Nothing; • The floods came when the maize crop was knee-high and all went with the floods; • Because the floods came with high-velocity winds, our iron sheets were removed by high winds from the roofs of houses.
	What did you do?	• Nothing.
	Who intervened and how?	• No one
	Was the intervention adequate?	• Not Applicable
	Is this a better approach in dealing with disasters?	• Not applicable
	What do you think are the causes of floods?	• Too much rain and nothing else; • Cutting down of trees near river banks; • Cultivating near or on river banks.
	Is the frequency of floods increasing or was it a once-off incident?	• I do not know because I have not kept any record; • Floods are occurring every year and 2006 was worse; • For the past 2-3 years, water levels have been normal; • Floods come after several years and occur unexpectedly when we thought they will never come again.
	What should be done of these events and by whom?	• No idea; • Stop cultivating near or on river banks; • Plant trees near river banks and upstream; • Planting trees in the catchment will result in less erosion and silt deposition in the river channel.

		• Plant trees **<u>in</u>** the river channel including reeds and bananas…but then, on second thought, these can be eroded away.
Economic aspects related to communities		
	What are your main food and cash crops?	• Maize, tobacco, soya, groundnuts; • Cotton; • Pigeon peas, beans.
	How long have you grown these crops?	• Since 2005; • Since we were born.
	Is there an increasing trend in income from the cash crop?	• Decreasing; • Increasing.
	If it is tobacco that is the cash crop, what curing methods do you use?	• Sun curing using sheds; • We will try flue-cured tobacco this year (2014 – 2015)
	Which areas do you get material for curing the tobacco?	• Near the river; • From Manyani Forest; • From our garden.
	What livestock do you keep?	• Cattle and pigs; • Goats and chickens; • Goats; • None.
	What was your annual household income (last year)?	• MK40,000.00[5] • MK50,000.00 • MK80,000.00 • MK100,000.00; • MK400,000.00; • MK540,000.00 • I do not know.
	Is your economic status satisfactory?	• No.
	What must be done to improve it farther?	• Our earnings only come once a year and it is better to go into business. This requires that the

[5] 1 US$ is equivalent to about MK350

		government or any other organisation should provide us with initial capital which we cannot get at the moment; • There is no alternative. We will continue with growing of tobacco as it is the main household income earner; • We will need to diversify the crops we grow. Apart from tobacco, we will try soya as a cash crop; • Government should continue with its One cow/goat per Family Programme as this can tremendously assist us at the household level.
	What are the constraints?	• Initial capital.
Environmental aspects related to communities		
	Do you think your activities on the environment do influence the levels of flooding?	• I do not know; • Yes – cutting down of trees; • We cannot support the cutting down of trees needed for construction of tobacco sheds during curing of the leaf.
	What are the main causes of floods in your view?	• As said, this is mainly because we cut down trees. Those tobacco farmers who are cutting down trees must be encouraged to plant 10 trees for every tree they cut.
	Are there any indigenous knowledge systems that can be used in predicting floods?	• None I know of.
	If yes, what are they and can they be used with confidence?	• Not applicable

	What must be done to reduce incidences and magnitudes of floods and their impacts?	• I have no idea; • These are natural events; • Reduction in the rate we cut down trees; • We need not cultivate near the river banks.
	Are you aware of the current laws governing natural resources management?	• Not all people know of these laws. As for me, all I know is that we should not cut down trees wantonly; • I do not know of any law related to the environment; • People are not aware…I do not know any laws about the environment. It is only the bosses who sit in Lilongwe who know of the laws you are asking about; • They do not make any effort to teach us about these laws.
	What is your level of engagement in natural resources management and how has such engagement contributed to sustainability of resources?	• I do not; • I must confess, I do not because I am also one of those who cut down trees…and I think this is why the rains are a problem these days; • Yes, I do by planting blue-gum (eucalyptus) trees; • Yes. I planted 14 trees in 2013 but some have been "eaten" by termites.